

AD-A091 959

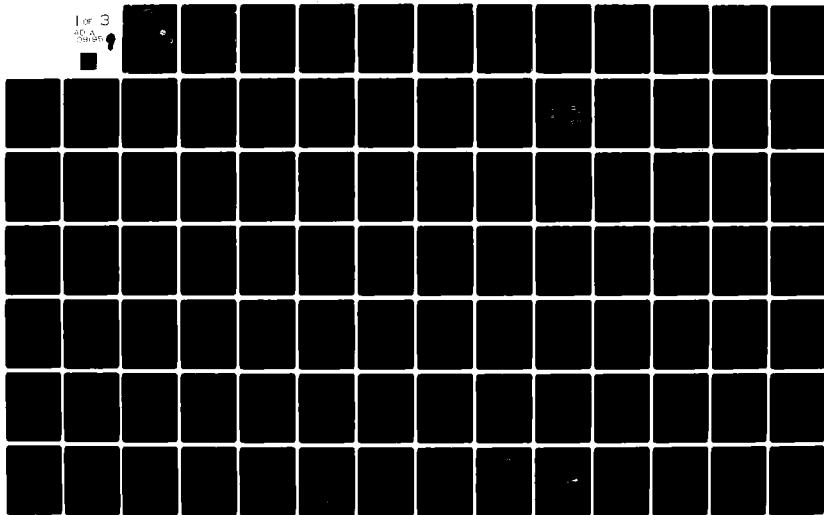
GENERAL ELECTRIC CO LANHAM MD SPACE DIV
ADVANCED SATELLITE HARDWARE/SOFTWARE SYSTEM STUDY.(U)
APR 80 R SPENCER, R HO, F KABAT, D M SMITH
A0S054213 ETL-0225

F/B 22/2

UNCLASSIFIED

DAAK70-79-C-0009
NL

1 of 3
AD-A
Order



ETL 0225

LEVEL *II*

P

ADVANCED SATELLITE HARDWARE/SOFTWARE SYSTEM STUDY

AD A091959

General Electric Co.
Space Division
Lanham Center Operations
4701 Forbes Boulevard
Lanham, Maryland 20801



DTIC
ELECTE
NOV 18 1980
S **D**
C

15 April 1980

FINAL REPORT

Approved for public release; distribution unlimited.

Prepared for:

U.S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060

8011 17 011

FILE COPY

Destroy this report when no longer needed.
Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The citation in this report of trade names of commercially available products does not constitute official endorsement or approval of the use of such products.

ERRATA SHEET

ETL REPORT NO. ETL-0225

Advanced Satellite Hardware/Software System Study

Page 43, second column: Change second occurrence of North Atlantic to South Atlantic.

Page 82, page sequence: Page inadvertently printed on the back of page 78.

Page 102, line 4: Change one to read on.

Page 115, line 5: Change work to read word.

Page 116, line 5: Change processors to read host, CPU.

Page 203, table 8-2: Replacement page 202/203 provided.

Page 205, line 16: Change 13.8 to read 6.9.

Table 8-2. Hardware Matrix for the Candidate Configurations

CONFIGURATION OPTION	EQUIPMENT DESCRIPTION	UNIT PRICE	NUMBER REQUIRED	TOTAL PRICE	COST INFORMATION
<u>STAND ALONE TERMINAL</u>	MINICOMPUTER (PDP11/70)	160K			DEC CATALOG
	DISK STORAGE (300 MB)	30K			VENDOR CATALOG
	CCT UNITS (2 EA)	72K			VENDOR CATALOG
	FILM RECORDER	120K			OPTRONICS CATALOG
	ARRAY PROCESSOR	80K			VENDOR QUOTE
	IMAGE ANALYSIS CONSOLE	130K			COMTAL CATALOG
	ALPHA/GRAPHICS TERMINAL	18K			VENDOR CATALOG
	PRINTER/PLOTTER	15K			VENDOR CATALOG
	TOTAL	625K	20	12.3 MILLION	
<u>COLLOCATED MULTI-TERMINAL</u>	<u>HOST SYSTEM:</u>				
	COMPUTER (VAX 11/780, 3 EA.)	1000K			DEC CATALOG
	DISK STORAGE (300 MB, 20 EA.)	600K			VENDOR CATALOG
	CCT UNITS (12 EA.)	432K			VENDOR CATALOG
	LASER BEAM RECORDER (2 EA.)	1250K			GE ESTIMATE
	ARRAY PROCESSOR (3 EA.)	240K			VENDOR QUOTE
	MISC. PERIPHERALS (PRINTERS, ETC.)	150K			GE ESTIMATE
	TOTAL	3672K	1	3.7 MILLION	
	<u>TERMINALS:</u>				
	IMAGE ANALYSIS CONSOLE	130K			COMTAL CATALOG
	ALPHA/GRAPHICS TERMINAL	18K			VENDOR CATALOG
	PRINTER/PLOTTER	15K			VENDOR CATALOG
	TOTAL	163K	20	3.3 MILLION	
	TOTAL SYSTEM COST			7.0 MILLION	

Table 8-2. Hardware Matrix for the Candidate Configurations (Continued)

CONFIGURATION OPTION	EQUIPMENT DESCRIPTION	UNIT PRICE	NUMBER REQUIRED	TOTAL PRICE	COST INFORMATION
<u>REMOTE MULTITERMINAL</u>	<u>HOST SYSTEM:</u>				
	SAME AS COLLOCATED	3672K	1	3.7 MILLION	
	MULTITERMINAL SYSTEM				
	<u>ANALYST TERMINALS:</u>				
	IMAGE ANALYSIS CONSOLE	130K			COMTAL CATALOG
	MINICOMPUTER (PDP 11/34)	140K			DEC CATALOG
	CCT UNIT	36K			VENDOR CATALOG
	DISK STORAGE (300MB)	30K			VENDOR CATALOG
	ALPHA/GRAPHICS TERMINAL	18K			VENDOR CATALOG
	PRINTER/PLOTTER	15K			VENDOR CATALOG
	TOTAL	369K	20	7.4 MILLION	
	TOTAL SYSTEM COST			11.1 MILLION	
<u>CUSTOMIZED STANDALONE TERMINAL</u>	<u>HOST PROCESSOR SYSTEM</u>				
	MINICOMPUTER (PDP 11/70)	160K			DEC CATALOG
	CCT UNITS (2 EA.)	72K			VENDOR CATALOG
	FILM RECORDER	120K			OPTRONICS CATALOG
	ARRAY PROCESSOR	80K			VENDOR QUOTE
	PRINTER/PLOTTER	15K			VENDOR CATALOG
	TOTAL	447K	11	4.9 MILLION	
	<u>ANALYST TERMINALS:</u>				
	IMAGE ANALYSIS CONSOLE	130K			COMTAL CATALOG
	ALPHA/GRAPHICS TERMINAL	18K			VENDOR CATALOG
	DISK STORAGE (300 MB)	30K			VENDOR CATALOG
	TOTAL	178K	20	3.6 MILLION	
	TOTAL SYSTEM COST			8.5 MILLION	

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
1. REPORT NUMBER ETL-0225	2. GOVT ACCESSION NO. AD-A091959	3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Advanced Satellite Hardware/Software System Study		5. TYPE OF REPORT & PERIOD COVERED Contract Report	
6. AUTHOR(s) R. Spencer D. M. Smith R. Ho R. Fries F. Kabat G. Hicks		7. PERFORMING ORG. REPORT NUMBER 80SDS4213	
8. PERFORMING ORGANIZATION NAME AND ADDRESS General Electric Space Division 4701 Forbes Blvd. Lanham, Maryland 20801		9. CONTRACT OR GRANT NUMBER(s) DAAK 70-79-C-0009	
10. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Engineer Topographic Laboratories Fort Belvoir, Va. 22060		11. REPORT DATE 15 Apr 1980	
12. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 237		13. NUMBER OF PAGES	
14. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		15. SECURITY CLASS. (of this report) Unclassified	
16. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
17. SUPPLEMENTARY NOTES			
18. KEY WORDS (Continue on reverse side if necessary and identify by block number) Landsat-D; Thematic Mapper Digital Data Analysis; Image Data Analysis Systems; Digital Image Processing			
19. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report provides an overview of the Landsat-D program and the anticipated requirements of the Corps of Engineers for the application of Landsat data to operational programs. A general discussion of the candidate data analysis requirements, including data input and output and other data preparation processes provides a complete description of the capabilities which will be required of an advanced satellite hardware/software image analysis system. A brief overview of the currently available hardware technology provides a basis for the synthesis of the hardware system design, and an example of a typical			

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

412053

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Software structure, based on that for an actual system, is presented. Descriptions of three candidate system architectures provide examples of different approaches to the development of a system meeting the Corps of Engineers requirements, and the problems of communication between remoted terminals and a host processor are addressed, together with the problems related to the dissemination of data to remotely located independent systems. A brief cost analysis indicates the system cost drivers, and shows how cost tradeoffs may be made in developing a specific system. A candidate system design for the Corps of Engineers is presented, based on the concept of independent systems with capabilities tailored to local requirements.

Accession For		<input checked="checked" type="checkbox"/>
DTIC TAB		<input type="checkbox"/>
Unannounced		<input type="checkbox"/>
Justification		
By Distribution/		
Availability Codes		
Avail and/or		
Special		
Dist		
A		

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

SUMMARY

SECTION 1. CORPS OF ENGINEERS ACQUISITION OF LANDSAT-D DATA PRODUCTS

Provides an overview of the Landsat-D program, the Landsat-D Ground System, and a brief description of the complex geometric correction process for Thematic Mapper data.

SECTION 2. REQUIREMENTS ANALYSIS

Provides a brief overview of the Corps of Engineers projects to which Landsat data analysis may be applicable. It describes briefly how Landsat data may be used in the conduct of these projects, and indicates the type of information management and data processing required.

SECTION 3. IMAGE ANALYSIS CAPABILITIES REQUIREMENTS

This section provides a detailed overview of the analysis required to extract the desired information from Landsat data and provide suitable image displays and output products. Techniques described range from simple data I/O manipulations, radiometric corrections and processing manipulations, to single band image analysis such as contrast enhancement and contrast stretching and complex multiband image analysis techniques of image classification using both simple (parallelepiped) and complex (Gaussian maximum likelihood) classifiers. Typical algorithms and analysis procedures for these techniques are described.

SECTION 4. HARDWARE CAPABILITIES

Provides a description of the state of the art in available hardware for the different functions of the system. Data I/O devices described include magnetic

tape devices, both CCT and high density (HDT) used by Landsat-D; optical disks, which use laser recording techniques; and film image scanners and film recorders. Data storage devices discussed are magnetic disk and, for online storage at an image display terminal, solid state refresh memory. Display devices for both image data and alphanumeric/graphics displays are introduced. For data processing, the discussion introduces the concept of the host processors as a general purpose computer, supplemented by special purpose hardware (such as table lookup processing), and array processors are introduced as programmable, high speed arithmetic devices. A short discussion of human factor elements describes the operator's interface to the system through a keyboard, joystick, trackball and other devices.

SECTION 5. SOFTWARE

This section describes a typical software structure, based on that developed for an actual system delivered, for the required system and applications software. The purpose of each of the system modules is described, and the manner in which it is applied and operated is presented.

SECTION 6. SYSTEM CONSIDERATIONS

This section describes three candidate system architectures: multiple independent systems; central processing system which collocated terminals; and a central processing system with remotely distributed terminals. A description of a typical interactive terminal design is presented, and the two major problem areas of communications between remote terminals and a central processor and of image data dissemination after receipt from Landsat-D are introduced and potential solutions discussed.

SECTION 7. COST ANALYSIS

This section introduces the cost drivers for different system designs, and shows how a cost model for candidate systems may be constructed. From the cost models and actual cost of hardware and estimated cost of software development cost tradeoffs may be developed for both the initial system cost comparison, and for life cycle cost of candidate systems.

SECTION 8. CORPS OF ENGINEERS SYSTEM

This section brings together the requirements and hardware and software capabilities described in earlier chapters, and suggests an approach to satisfying the Corps' system requirements based on the implementation of independent image analysis systems, each tailored to the regional geographic requirements of the various COE districts and laboratories.

PREFACE

This report was prepared under contract DAAK 70-79-C-0009 for the U.S. Army Corps of Engineers, Engineer Topographic Laboratories, Fort Belvoir, Virginia. The Contracting Officers Technical Representative was Mr. Richard D. Tynes.

TABLE OF CONTENTS

SECTION		PAGE
1	CORPS OF ENGINEERS ACQUISITION OF LANDSAT-D DATA PRODUCTS	1
	1.1 Introduction and Summary	1
	1.2 Landsat-D Ground Segment Overview	3
	1.3 Mission Management Facility	5
	1.4 Image Generation Facility	8
2	REQUIREMENTS ANALYSIS	18
	2.1 Corps of Engineers Projects	18
	2.2 General Applications of Landsat Data	22
	2.3 Landsat Data Characteristics	24
	2.4 Application Scenarios	28
	2.5 Information Management	41
	2.6 Data Processing Requirements	42
3	IMAGE ANALYSIS CAPABILITIES REQUIREMENTS	49
	3.1 Introduction	49
	3.2 Data Input/Output	50
	3.3 Data Preparation and Display Control	52
	3.4 Data Correction	54
	3.5 Single Band Image Analysis	54
	3.6 Spectral Signature Analysis	57
	3.7 Post Processing Procedures	88
	3.8 Mensuration	88
4	HARDWARE CAPABILITIES	90
	4.1 Data Input and Output Devices	90
	4.2 Data Storage and Display	96
	4.3 Data Processing Systems	107
	4.4 Human Factors Elements	117
5	SOFTWARE	121
	5.1 System Software	121
	5.2 Application Software	125
6	SYSTEM CONSIDERATIONS	172
	6.1 System Concepts	172
	6.2 Interactive Terminal Design	180
	6.3 Remote System Communications	185
	6.4 Image Data Dissemination	189
7	COST ANALYSIS	191
	7.1 Cost Tradeoffs	191
	7.2 System Cost Drivers	192

TABLE OF CONTENTS

SECTION	PAGE
8	THE CORPS OF ENGINEERS SYSTEM
8.1	Systems Requirements Analysis
8.2	Candidate System Designs
8.3	System Selection
9	CONCLUSIONS
APPENDIX A	THEMATIC MAPPER GEOMETRY
REFERENCES	
LIST OF ABBREVIATIONS	

LIST OF ILLUSTRATIONS

FIGURE		PAGE
1-1	The Landsat-D Ground System	4
1-2	Mission Management Facility	6
1-3	Image Generation Facility	11
1-4	Image Generation Process Flow	12
1-5	Summary of Geometric Correction Matrices	15
2-1	Landuse Mapping - Change Detection Data Processing Flow	31
2-2	Geologic Studies - Structural Mapping Data Processing Flow	34
2-3	Hydrology/Hydraulics - Drainage Basin Mapping Data Processing Flow	36
2-4	Coastal Studies - Water Penetration/Shoaling Data Processing Flow	38
3-1	Contrast Stretch Algorithms	56
3-2	Typical Multispectral Signatures	58
3-3	Two-Dimensional Cluster Plots	59
3-4	Normalization	62
3-5	Spectral Rotation - Dimensionality Reduction	65
3-6	Signature Analysis Techniques	66
3-7	Single Cell Signature Analysis	68
3-8	Single Cell Signature Analysis	70
3-9	Single Cell Signature Acquisition	70
3-10	Histogram Limit Modification	71
3-11	Spectral Rotation	72
3-12	Multicell Signature Acquisition	73
3-13	Multicell Signature Acquisition	75
3-14	Thresholding	75
3-15	Two-Dimensional Histogram Display	76
3-16	Gaussian Signature Analysis	78
3-17	Geometrical Interpretation of Eigenvectors	79
3-18	Cluster Analysis	80
3-19	Cluster Analysis (Two Cluster Case)	81
3-20	Classifiers	83
3-21	Nonparametric Maximum Likelihood	84
3-22	Parametric Maximum Likelihood Classification	86
3-23	Minimum Distance Classification	87
4-1	Comparative Storage Capacity of Different CCT Formats	94

LIST OF ILLUSTRATIONS

FIGURE		PAGE
4-2	Image Analysis System Concept	108
5-1	Application Software Overview	126
5-2	Frame to Scene Mapping	129
5-3	Bias and Gain Computations	132
5-4	Skew Correction	142
5-5	Spatial Formatting	145
5-6	Nearest Neighbor Resampling	147
5-7	Cubic Convolution Resampling	148
5-8	Histogram Display/Modification	157
6-1	Standalone System Configuration	175
6-2	Collocated Multi-Terminal System	178
6-3	Image Analysis Terminal	182
6-4	Standalone Image Analysis System	186
A-1	Thematic Mapper Optical System	207
A-2	TM Detector Array Projection Along Scan	209
A-3	Scene Conditions at the Equator	210
A-4	Thematic Mapper Detector Arrays	213
A-5	Detailed Detector Layouts	214
A-6	Ground Pixel Pattern for Bands 1, 2, 3, 4, 5, 7 West to East Scan	216
A-7	Ground Pixel Pattern for Bands 1, 2, 3, 4, 5, 7 East to West Scan	217
TABLE		
1-1	IGF Requirements	9
2-1	Relationship Between COE Activities and Applications/Techniques	19
2-2	Ranking of Specific Applications/Extraction Processing Techniques	20
2-3	Geometric Accuracy of Processed TM Data	25
2-4	TM and MSS Spectral Responses	26
2-5	Overview of Data Processing Requirements for Four COE Activities/Applications	30
2-6	Functional Time Requirements	40

LIST OF ILLUSTRATIONS

TABLE		PAGE
2-7	TM Scene Requirements (No Cloud Adjustment)	43
2-8	Estimated TM Scene Processing Requirements	46
2-9	Estimated TM Scene Archive Requirements	47
2-10	Scene Archive Requirements by Division	48
3-1	General Factors that Product Signal Variations	62
4-1	Relationship Between CPU Functional Capabilities and Image Analysis System Functional Requirements	111
6-1	Data Transmission Times in Seconds for 512 X 512 Pixel Images	188
7-1	Hardware Cost Estimates (in Thousands of Dollars)	193
8-1	Data Requirements by Division	198
8-2	Hardware Matrix for the Candidate Configurations	202
8-3	Cost Comparison Between Configuration Options (in Millions of Dollars)	204
A-1	Detector Sampling Scheme and Pixel Numbering	212

SECTION 1

CORPS OF ENGINEERS ACQUISITION OF LANDSAT-D DATA PRODUCTS

1.1 INTRODUCTION AND SUMMARY

This report was written during a period (January 1980) of confusion with regard to the finalization of plans concerning the availability of Landsat-D data products to the user community. In November of 1979, the President designated the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) to manage all operational civilian remote sensing activities from space. The first spacecraft that may be affected by the transition to NOAA is Landsat-D. Although officially designated as an experimental satellite, the Landsat-D spacecraft's payload includes a multispectral scanner (MSS) which represents a continuation of Landsat data that has been utilized for eight years and is thought of as operational by much of the user community. Landsat-D and D-prime also carry a thematic mapper (TM) instrument which is experimental and is intended to act as a transition sensor for operational satellites to be developed in the future.

Two key issues for Landsat data users are future data costs and availability. NOAA has a special committee studying data costs and already has indicated that costs will increase significantly for both foreign and domestic users of Landsat data in an effort to make the remote sensing program self-supporting. NOAA is also studying whether or not it should assume control of USGS's EROS Data Center (EDC), the current national dissemination center for Landsat data in Sioux Falls, South Dakota. No other facility is currently equipped to provide this service and EDC has made some plans to be able to handle Landsat-D MSS and TM data in preparation for a 1981 launch. To date, however, EDC has not initiated the procurement of equipment to be able to handle thematic mapper 28-track high

density digital tapes within their facility. NASA has specified that the Landsat-D Ground Segment be able to provide the high density tapes for EDC but has not provided for a Domsat link of TM data.

Although the handling of MSS data from Landsat-D should represent an improvement in turnaround time from the current Landsat system, the availability of thematic mapper data represents a revision to the film-only system utilized eight years ago with the advent of Landsat 1. The planned NASA Landsat-D ground system is designed to provide only ten equivalent full scenes of TM data per day in a CCT format that users order through EDC from those TM scenes that are entered into the EDC data base from the film products produced (less than or equal to 50 scenes per day). NASA has also indicated that it will not provide Landsat digital data products directly to other agencies as it has in the past although the capability has been designed into the NASA Ground Segment. These ground rules would suggest a serious lack of digital TM data availability for the Corps of Engineers.

In addition, the improved performance requirements for TM data result in very complex and costly geometric correction processing, and will most likely result in making the use of ungeometrically corrected TM data totally impracticable for the user community.

In this section, it is our intent to provide additional detail on the NASA Landsat-D processing system and on the complexities foreseen in processing ungeometrically corrected TM data. Although the final design of the TM processing necessary to overcome recently discovered geometry problems has not been completed, some impacts to the data products will be described. For the sake of brevity, it has been assumed that the reader is familiar with Landsat 1, 2, and 3 data processing and distribution systems and further, that the reader

is aware of the major characteristics of the multispectral scanner and thematic mapper sensors.

1.2 LANDSAT-D GROUND SEGMENT OVERVIEW

The NASA portion of the Landsat-D ground system is comprised of five major elements (see Figure 1-1). The Mission Management Facility is the controlling element of the entire ground system. It schedules all data acquisition and transmission activities for the Flight Segment and controls all production throughout the rest of the NASA portion of the ground system. It maintains the data base of what has been requested, what is to be acquired, and what has been acquired.

The Control and Simulation Facility provides online evaluation of Flight Segment telemetry data, generates and transmits commands to the Flight Segment and includes a Flight Segment simulator for use in test and operator training. The Image Generation Facility includes all the equipment necessary for receipt and recording of wide band image data and performs radiometric and geometric corrections on this data. The Transportable Ground Station receives direct

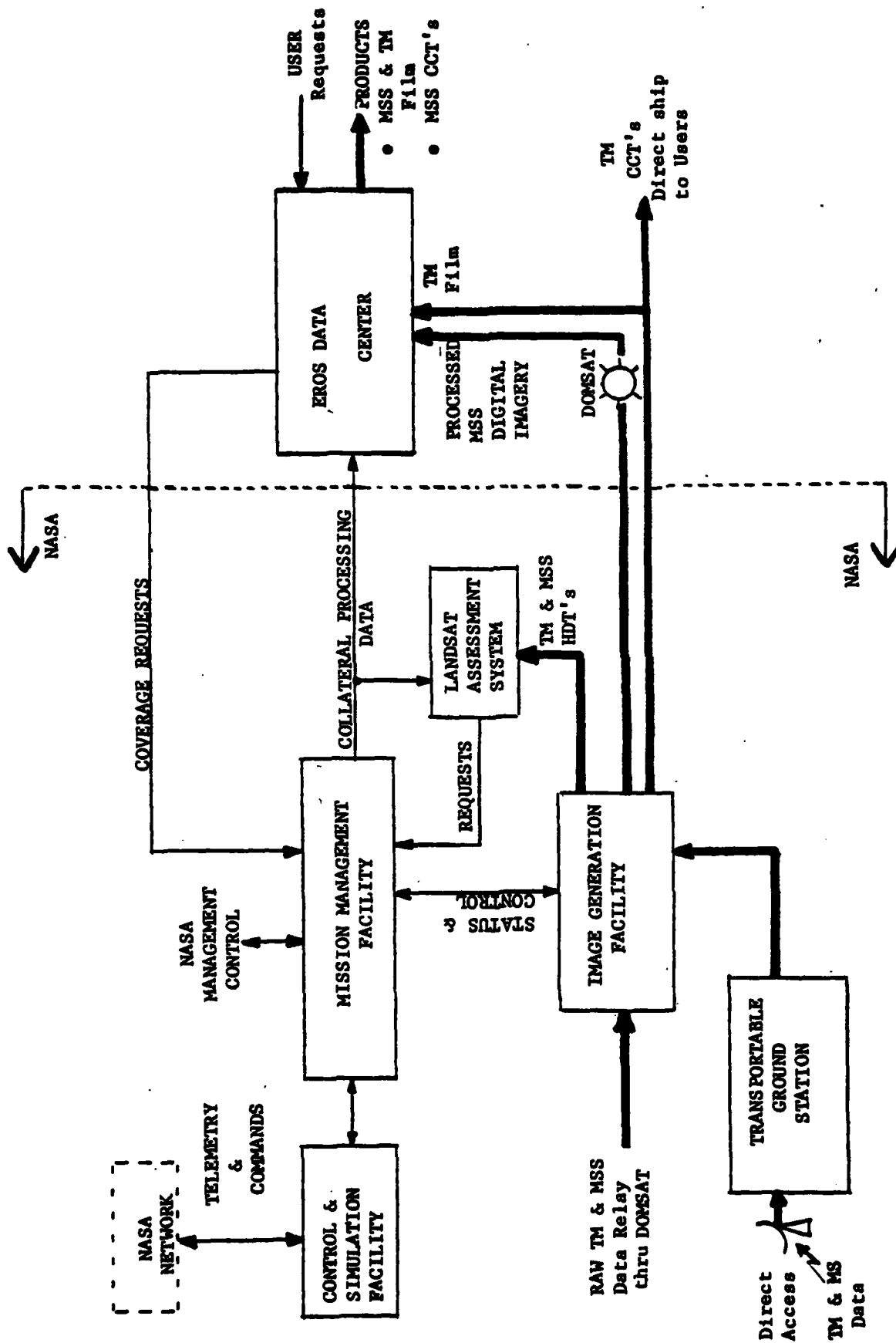


Figure 1-1: The Landsat-D Ground System

broadcast TM and MSS data. This system will be used for engineering evaluation tests of the direct broadcast downlinks. The Landsat Assessment System is a NASA research facility that provides image processing and analysis capabilities for the continued investigation and development of Earth resources management techniques using data from both the TM and MSS sensors.

The NASA Ground Segment is a totally new undertaking by NASA. It will be housed in a separate building currently under construction at the Goddard Space Flight Center. Since Landsat-D incorporates a new sensor, an entirely new spacecraft design, a multi-satellite real-time communication link, and new processing requirements, the Landsat-D system is being developed totally independent from the existing Landsat system. Subsequent paragraphs will briefly summarize the requirements, configuration, and capabilities of only the Mission Management Facility and the Image Generation Facility as being pertinent to the scenario of data acquisition by the Corps of Engineers.

1.3 MISSION MANAGEMENT FACILITY (MMF)

The MMF includes four subsystems: Request Support, Flight Segment Management, Ground Segment Management and Data Base Administration. These subsystems and their major interfaces are shown in Figure 1-2.

Request Support and Flight Segment Management interact with elements external to the Landsat-D system that support the scheduling of Flight Segment activities. User requests for coverage and products directly determine the imaging of particular areas of the world. Cloud cover predictions from NOAA influence when high quality imagery can be acquired. The Space Tracking and Data Network

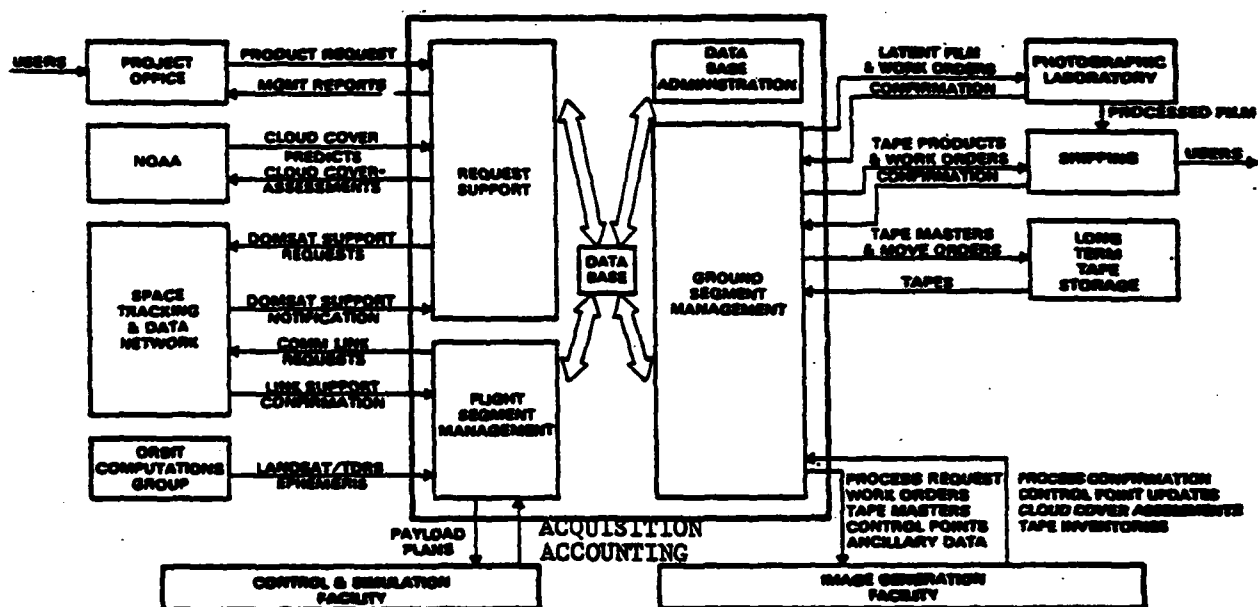


Figure 1-2. Mission Management Facility

provides both TDRS and Domsat support for relay of data to GSFC. The Orbit Computation Group supplies the orbital characteristics of both Landsat and TDRS for both geographic coverage planning and Flight Segment antenna pointing. All of this information is stored in the data base, operated on by the Flight Segment Management Subsystem and converted into specific plans for Flight Segment payload operations. The payload operations plans are then transferred to the Control and Simulation Facility for conversion into command sequences for transmission to the Flight Segment.

The Ground Segment Management Subsystem controls the flow of data to and from the Image Generation Facility (IGF) and controls the process flow in the IGF. It also controls the transfer of latent film imagery to the photographic laboratory and the shipment of processed film and tape products to users. Since the Ground Segment will maintain only a six-month tape archive, Ground Segment management also controls the transfer of tapes to and from a long-term tape storage facility. Control functions are implemented via both hard copy and CRT displays of work orders or by process requests where computer-to-computer communications are employed.

The MMF also generates computer compatible tapes consistent with the output products that are shipped to the the EROS Data Center. These tapes contain the collateral processing data necessary to be able to generate a data base at Sioux Falls of what data they have available. These tapes also have ancillary processing data to allow EROS Data Center to apply the correction factors to the semi-processed MSS high density digital tapes that they receive from NASA. This information will be transmitted directly to Sioux Falls via telephone network. The collateral data also include information concerning the TM film and MSS HDT products that are provided by NASA to EROS Data Center. However, the EROS Data

Center data base will not contain coverage information for those TM scenes that have not been converted to film. The NASA portion of the Landsat-D Ground Segment will schedule approximately 100 TM scenes per day, process 50 of those scenes through full corrections, and then provide 50 or fewer TM scenes to the EROS Data Center as a film product. It is only these final 50 scenes or less that are known within the EROS Data Center data bank. It is from this latter group that users may request that CCTs of TM data be provided to them. These requests are then retransmitted back to NASA through the Mission Management Facility and scheduled to be generated within the Image Generation Facility. Approximately ten equivalent full scene CCTs will be generated per day and shipped directly to the original requestor.

1.4 IMAGE GENERATION FACILITY (IGF)

The IGF receives and records all wideband image data, radiometrically and geometrically corrects the image data and generates output products for users. The key requirements on the IGF are shown in Table 1-1. Taken together, these requirements define a high volume, high accuracy, short turnaround production system capable of sustaining operation with single point failures. This is the major challenge in the Ground Segment.

Table 1-1. IGF Requirements

- RECEIVE/RECORD SENSOR DATA
- RADIOMETRIC CORRECTION
 - THROUGHPUT (SCENES PER DAY)
 - 10 TM TO HDT-ARCHIVE
 - 200 MSS TO HDT-ARCHIVE
 - ACCURACY
 - ± 1 QUANTUM LEVEL
- GEOMETRIC CORRECTION
 - THROUGHPUT (SCENES PER DAY)
 - 50 TM TO HDT-PRODUCT
 - 50 TM TO 241 MM FILM
 - 10 TM TO CCT
 - ACCURACY
 - REGISTRATION: 0.3 PIXEL (90%)
 - GEODETIC: 0.5 PIXEL (90%)
- MAX TURNAROUND TIME - 48 HOURS
 - RAW DATA TO ANY PRODUCT
 - WITH ANY SINGLE FAILURE
- MAX UTILIZATION - 85% OF 16 HOURS
 - WITH ANY SINGLE FAILURE

1.4.1 IMAGE GENERATION REQUIREMENTS

The IGF consists of three subsystems (Figure 1-3): Data Receive, Record and Transmit Subsystem; Image Processing Subsystem, and Product Generation Subsystem. The Data Receive, Record and Transmit Subsystem receives raw TM and MSS data from both the Domsat terminal and the Transportable Ground Station and routes the data to a bank of high density digital recorders (HDDR). Routing of the data both into the recorders and later to and from the processing strings is controlled by a computer acting under the direction of the Image Generation Facility. The bank of recorders supports all processing functions.

The raw data are then played back into one of the two processing strings of the Image Processing Subsystem where information is extracted to allow the calculation of geometric correction matrices, radiometric correction functions, cloud cover percentage and various forms of annotation data to allow identification of the image (Figure 1-4). Computations are performed on the extracted information while the tape is being rewound; it is then applied during a second playback of the tape. The resulting tape, at this point, is called a high density tape - archival (HDT-A); it has radiometric corrections applied, and geometric correction matrices appended (but not applied). For MSS data, the data on this tape are then relayed via Domsat to the EROS Data Center for distribution to users. For TM data, the tape can be further processed at NASA to have the geometric correction matrices applied, which results in a fully corrected tape called a high density tape product (HDT-P).

The product tape can then be switched to the Product Generation Subsystem and used either to generate 241mm film on a laser beam recorder or to transfer image data to 1600 or 6250 bits per inch computer compatible tapes. Copies of the

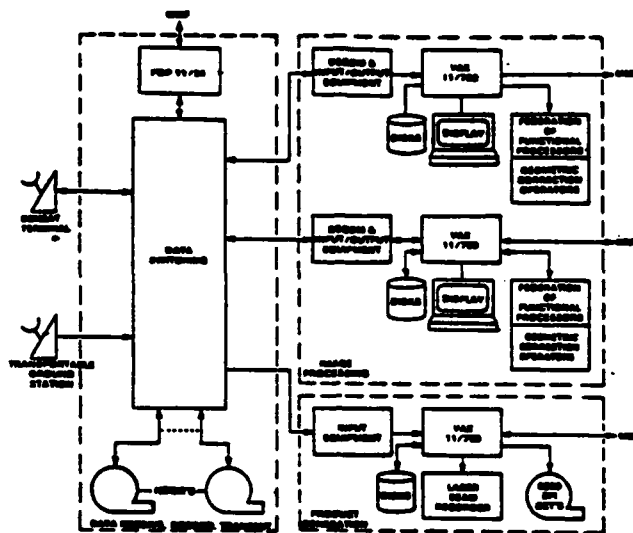


Figure 1-3. Image Generation Facility

high density tapes are generated directly in the Data Receive, Record and Transmit Subsystem. Copies of the CCTs are generated within the Mission Management Facility.

All TM and MSS scenes are radiometrically corrected to ± 1 quantum level on the archival tape; a combination of instrument calibration data and information extracted from the content of the scene is used to generate the radiometric calibration functions. Image striping, which was prevalent in earlier Landsat imagery, will be avoided by the processes used on Landsat-D.

Geometric accuracies are achieved by control and modeling of over 80 different error sources. These error sources include Flight Segment vibration and thermal bending as well as instrument scan nonlinearities and altitude effects that were

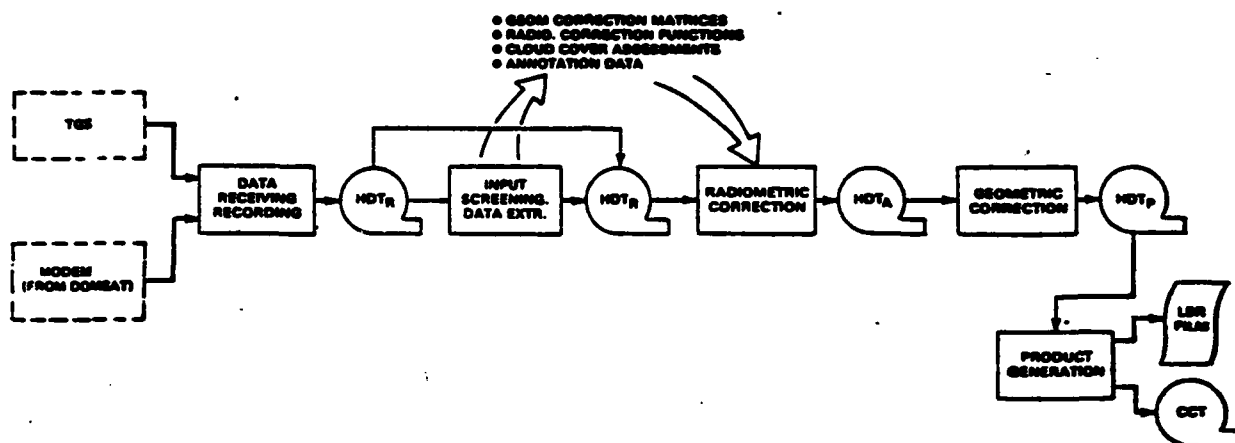


Figure 1-4: Image Generation Process Flow

not required in correction techniques utilized for Landsat 1, 2, and 3. All data on the archival tapes will have the geometric corrections calculated and appended to the tape. Product tapes of the TM data will be generated at GSFC for 50 scenes per day and will have the imagery resampled and the radiometric corrections applied. Users will be able to obtain the resampled imagery with these corrections in Universal Transverse Mercator, Polar Stereographic or Space Oblique Mercator map projections.

The application of the geometric corrections consumes the most processing time since the resampling process must be performed on each and every picture element. General Electric Federation of Functional Processor (FFP) Computers, originally developed for sonar signal processing, are utilized in each of the image processing strings to perform the geometric correction process. The FFPs

each employ two hardware elements called geometric correction operators which have been specifically designed to perform the resampling function at very high bit rates. This unique combination of general purpose computers and special purpose hardware allows the 48-hour turnaround time to be met with an additional margin.

This margin, coupled with built-in redundancy, also allows the IGF to meet its throughput requirement with single point failures. Complete redundancy exists in the two image processing strings allowing generation of archival and product tapes with any single failure. Where a single item of equipment exists, such as the Laser Beam Recorder, all other production can continue with a failure in that item, with data stored on disk or tape. The appropriate portion of the facility can then be dedicated to the recovery process once the failed equipment is back on line.

1.4.2 TM GEOMETRIC CORRECTIONS - OVERVIEW

Both NASA and EROS Data Center personnel recognize the desire of many users to obtain unresampled image data, but the complexities involved in TM geometric correction make it much more impractical for the user community to process this data than is the case for Landsat MSS data. The solution to the problem of geometric correction of thematic mapper data has not been finalized at this date, but a reasonable approach has been established. The consequences of this approach are discussed in the paragraphs that follow.

It should be remembered that TM geometric correction processing represents an order of magnitude change over that required for MSS processing. The correction of TM data to the sub-pixel level requires improved accuracy in the knowledge of spacecraft position, spacecraft attitude, scan mirror position, time, and many other parameters as required for systematic geometric corrections. In addition,

both relative and absolute geometric correction knowledge is required to the sub-pixel level to allow radiometric corrections not to be in excess of ± 1 quantum level. The systematic geometric corrections necessary are all relatively well known and are contained within a time invariant correction matrix that is referred to as the alpha matrix for each scene. The alpha matrix includes known ephemeris, Earth rotation, Earth geoid effects, perfect geodetic pointing of the TM optical axis, perfect scan mirror motion, and selected map projection values. The matrix is comprised of two words (X and Y locations) at each of 12 cross scan locations for each of 22 forward and back scan locations per scene. These 528 words per scene represent the time invariant alpha matrix that is based upon perfect performance of spacecraft pointing and TM operation. Thus, knowledge of the location of a relatively small number of pixels in scans spaced throughout the image is sufficient to describe the location of any other pixels in the scene. For thematic mapper data, however, it is necessary to superimpose upon this matrix the effects of high frequency spacecraft jitter, attitude errors, motion of the TM scan mirror and scan line corrector, band-to-band effects, and individual band misalignments in order to determine the true location of all pixels on the ground within the specified Landsat-D accuracies.

Figure 1-5 is a summary of the geometric matrices that must be folded together to provide the necessary geometric corrections to each TM scene. This 100 KB of ancillary data is included in the header of the semi-processed high density tape within the NASA ground processing system. It is easy to see the convenience of the multiple matrix form, since various combinations of the matrices must be folded together to apply the corrections to the TM data on a per band basis.

The additional matrices shown in Figure 1-5 represent corrections necessary to reflect the optical misalignments and dynamic nonlinearities of the TM and the

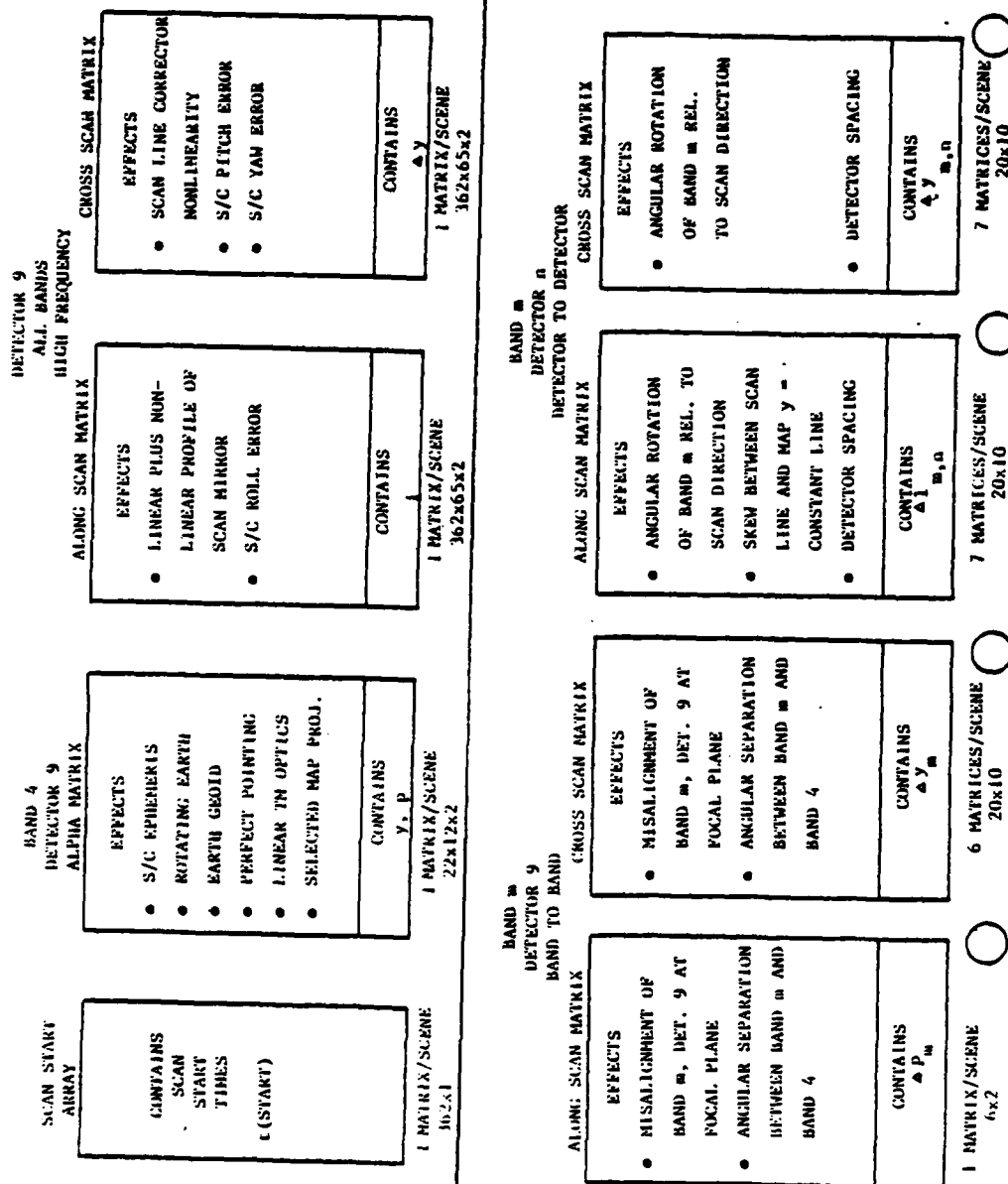


Figure 1-5. Summary of Geometric Correction Matrices

Landsat-D spacecraft pitch, roll and yaw attitude errors and high frequency jitter. Appendix A includes a description of the nominal TM scene, identifies the effect of taking data during both forward and reverse scan and the effects of the nominal layout of the detector array within the instrument's focal plane. The Landsat-D spacecraft has been designated by NASA as a Multi-Mission satellite (MMS) and has been configured with a large cantilevered antenna that tracks the Tracking and Data Relay Satellite System (TDRSS) to allow real-time communications between the spacecraft and the ground processing system. The TM, although derived from the MSS, represents a significant increase both in size and in the accuracies required to meet the overall Landsat-D performance. The oscillating scan mirror generates high frequency jitter in both the instrument and the spacecraft itself.

There are six matrices, which as a group are called the geometric correction matrices. They are shown in Figure 1-5 and are summarized as follows:

1. High Frequency Along Scan Matrix

Corrects for high frequency S/C roll jitter and TM scan mirror nonlinearity. Corrects the S/C attitude roll errors.

2. High Frequency Cross Scan Matrix

Corrects for high frequency S/C pitch and yaw jitter and S/C pitch and yaw attitude error. Corrects for TM scan line corrector nonlinearity.

3. Band-to-Band Along Scan Array

Provides angular separation between bands 1, 2, 3, 5, 6 and 7 relative to band 4 along scan direction. Also corrects for individual band displacements at the focal plane.

4. Band-to-Band Cross Scan Matrix

Corrects for angular separation between bands 1, 2, 3, 5, 6, 7 and band 4 along Y direction. Also corrects for individual band

displacements at the focal plane. Accounts for differing slant range across the scan.

5. Detector-to-Detector Along Scan Matrix

Relates:

- o Detector spacing along scan direction
- o Individual band rotations and skew between scan line and a map grid
- o Differing slant ranges along the scan.

6. Detector-to-Detector Cross Scan Matrix

Relates:

- o Detector spacing in cross scan direction
- o Individual band rotations
- o Differing slant range across the scan.

As a consequence of the current lack of knowledge of the availability of ungeometrically corrected TM data as discussed earlier, and the complexity and hence cost in terms of hardware and time involved in making the geometric corrections as indicated in the previous three paragraphs, it is recommended that the Corps of Engineers plan only to utilize fully radiometrically and geometrically corrected data for all subsequent processing. If there are experimenters within the Corps of Engineers who wish to utilize uncorrected TM data, they should endeavor to utilize NASA's Landsat Assessment System, which will have the capability to ingest and process ungeometrically corrected TM data. NASA will sponsor an Image Science Group who will identify and experiment on unprocessed TM data to develop new algorithms for TM data processing and analysis. Information concerning this facility and its availability for projects can be pursued through NASA Code 900 or the Landsat-D Project Scientist.

SECTION 2

REQUIREMENTS ANALYSIS

2.1 COE PROJECTS

COE efforts can be conveniently divided into ten "activities," which are an aggregation of a broad range of technical disciplines and organizational functions. A survey of COE Divisions and Districts on the use of remote sensing technology identified 41 specific applications or extractive processing techniques. Table 2-1 shows which of these applications/techniques are applicable to each of the ten activities. Table 2-2 orders the applications/techniques based on the number of activities that utilize each one. It should be noted that the importance of an application/technique for any activity is not indicated in Table 2-1. In addition, the various applications/techniques are not all comparable; some are very specific, such as Aquatic Weed Studies, others are general, such as Vegetation Identification, some are generic, such as Mapping/Mosaicking, and some are functions, such as Reservoir Management.

The entries in Table 2-2 appear to have five principal components: General Overviews, Mapping, Surface Classifications, Change Detection/Monitoring, and Mensuration. For example, Damage Studies look at changes, Habitat Studies are land type classifications, and Stream Parameters are mensuration. Most of the top ranked applications/techniques are covered explicitly by this new categorization. Other COE remote sensing applications also fall into these categories, indicating their general utility. The following paragraphs define

Table 2-2. Ranking of Specific Applications/Extraction Processing Techniques

NUMBER OF ACTIVITIES	APPLICATION/TECHNIQUE
8	Land Use Mapping
6	Mapping/Mosaicking
5	Changes/Change Detection
4	Damage Studies
	Drainage Basin Maps
	Permits & Enforcement
	Vegetation Identification
	Flood Delineation & Assessment
	Site Reconnaissance Studies
3	Historical Studies
	Hazard Assessment
	Synoptics & Overview
	Water Quality/Pollution Studies
2	Erosion/Nourishment studies
	Identification - Soils, Rock, Sand
	Ground Water & Seepage
	Wetlands Identification
	Environmental Assessment
	Bank Erosion
	Ice Studies
	Dredging Studies/Project
	Water Resources Plans
1	Coastal Studies
	Drift Pattern/Wave Analysis
	Water Penetration/Shoaling
	Inlet Studies
	Structural Mapping
	Geomorphic Mapping
	Reservoir Management
	Acquatic Weed Studies
	Waste Water Studies
	Stream Parameters (Lengths, etc.)
	Sediment/Deposition Studies
	Valley Cross Sections
	Environmental Impact Studies
	Habitat Studies
	Water Detection (Inventory)
	Heat Loss Studies
	Snow Cover/Runoff Prediction
	Construction Monitoring (clearing, excavating)
	Transportation/Route Plans

each category briefly and give some examples of the types of projects to which they are applicable.

General Overviews - To obtain a broad, comprehensive view of an area, including both the specific site and the relevant neighborhood, which could be quite large, such as a dredging operation in a major river or coastal region.

Mapping - To identify basic surface features such as roads, cities, shorelines, swamps, mountains, and snow cover.

Surface Classification - To differentiate between various surface (and subsurface) properties. This includes basic differences like grassland vs. forest vs. rock, and differences within a type, like oak forest vs. pine forest vs. mixed hardwood forest or sand vs. soil vs. rock. Such differences can be used as the basis for secondary distinctions such as delineation of erosion prone areas, wildlife habitats, and ground water locations. (The term "Land Use Classification/Mapping" could be used for this category; however, it usually implies a more restrictive definition.)

Change Detection/Monitoring - To discern the occurrence of changes, both rapid and slow, as the result of natural processes and human activity, such as river course changes, forest maturation, flood damage, and pollution. Also included are the changes in the rate of change, such as harbor siltation and shoreline migration. Another facet is looking for expected or potential changes, such as from construction activities.

Mensuration - to determine the size or length of map properties and surface classifications, and the magnitude of changes. An example is the area covered by snow, and also the extent of snow melt in a one-week period.

Because some of the 41 applications/techniques are not covered by these five categories, or a combination of them, especially multifaceted efforts such as water resources, historical studies, Environmental Impact Statement (EIS) preparation, and route planning, a final category, other, is necessary. This category would also include R&D studies that attempt to develop new techniques or new applications.

These six categories are much more manageable and more inclusive than the list of 41 applications/techniques, and present a clearer picture of COE endeavors.

2.2 GENERAL APPLICATIONS OF LANDSAT DATA

There are many areas where Landsat data are useful to the COE, as demonstrated by current usage. Because of its global, repetitive coverage Landsat can provide information not readily available elsewhere. In addition, the digital form of the data lends itself to direct computer processing, so that information can be extracted that could be very difficult and expensive to obtain manually, or by digitizing aircraft photographs. This means that analysis previously not attempted may become routine. The cost, time, and manpower required to gather required information are often reduced significantly, which clearly is a substantial benefit to be considered by the COE in deciding to expand the use of Landsat data.

Landsat data are useful in all phases of COE projects:

- a. Project planning - During the planning stage it is often necessary to have a general, but fairly detailed, view of the project site. This is helpful to determine where problems may arise and to estimate the resources required to perform the project. Landsat data are often more useful than a map because they contain a combination of information about vegetation, geology, land use patterns, etc. Scenes from different times of the year show seasonal variations and the typical sequence of natural events in a particular area. In addition, historical Landsat data (MSS from 1972, RBV from 1978, TM from 1981) can be very valuable as a baseline from which the effects of previous projects or natural phenomena can be determined.
- b. Project execution - In the course of a project a wide variety of information about the area of interest will be required. Because of its multispectral character Landsat data are particularly useful in differentiating between various surface characteristics, as diverse as vegetation types and urban land uses. For projects covering large areas or many sites the global view offered by Landsat often permits rapid accumulation of information in usable form, such as delineation of flood areas.
- c. Post-project analysis - After a project has been completed it is often desirable or necessary to examine the effects of the project, to see if they are what was expected. Comparisons of Landsat images taken before, during, and after can be used to see obvious results such as

sand bar movement, siltation, and reservoir filling, or more subtle results such as decreases in river pollution, habitat changes, and reduced erosion.

2.3 LANDSAT DATA CHARACTERISTICS

The basic characteristics of the Earth's surface that can be determined from Landsat TM data are:

- a. Spatial characteristics - Due to the properties of the TM instrument and the spacecraft orbit, the ground size of one detector's instantaneous field of view (IFOV), which is represented by one picture element (pixel) in the data, is a square 30m on a side (except for Band 6, in the thermal IR, for which it is 120m on a side). This determines the best possible resolution available from TM data. With on-ground processing the data can be converted to any map projection or registered to a previously processed image. Table 2-3 gives the geometric accuracies available with various types of processing. By comparison, the ground size of one detector's IFOV for the MSS is 80m square.
- b. Spectral characteristics - The TM collects data in seven spectral bands from the blue to the thermal IR, as shown in Table 2-4. The major difference from the MSS is the inclusion of the bands in the near IR and the thermal IR. These bands are expected to be especially useful for geologic investigations and thermal studies. Data will be collected by Band 6 during both daylight and nighttime passes.
- c. Temporal characteristics - The spacecraft orbit is selected so that it

Table 2-3. Geometric Accuracy of Processed TM Data

- Registration to Previous Image: 0.3 Pixel* (90%)
- Representation of Geodetic Surface, Using Ground Control Points:
0.5 Pixel (90%)
- Internal Distortions, No Ground Control Points or Registration Used:
0.2 Pixel (90%)
- Band to Band Registration: 0.2 Pixel (90%)

*For Bands 1-5 and 7, one pixel (picture element) is 30m square, for Band 6 one pixel is 120m square.

Table 2-4. TM and MSS Spectral Responses

TM & MSS Spectral Responses

THEMATIC MAPPER		MULTISPECTRAL SCANNER	
Spectral Band	Bandwidth	Spectral Band	Bandwidth
Number	(Micrometers)	Number	(Micrometers)
1	0.45 - 0.52	1	0.5 - 0.6
2	0.52 - 0.60	2	0.6 - 0.7
3	0.63 - 0.69	3	0.7 - 0.8
4	0.76 - 0.90	4	0.8 - 1.1
5	1.55 - 1.75		
6	10.40 - 12.50		
7	2.08 - 2.35		

has a fixed repeat cycle. For example, Landsats 1, 2, and 3 had orbits that resulted in their retracing the same ground track every 18 days. For Landsat-D (with the TM) the repeat cycle has not been finalized, but it probably will be either 16 or 20 days. Each ground track is 185km wide. Many ground areas are covered by more than one 185km wide ground trace. The higher the latitude of an area the more likely it is to be covered more often than once per cycle. For instance, some areas in Alaska are covered every several days. In addition, each pass over the same area occurs at the same local time; for the lower 48 states it was chosen to be about 9:30 am.

Comparing these characteristics of Landsat data with COE remote sensing requirements, as outlined in Section 2.1, a strong correlation is evident. In particular there is essentially a one-to-one correspondence between the three basic characteristics and four of the five categories:

- a. General Overviews - Satisfied by a combination of the spatial and spectral characteristics. Can use Landsat photographic products, either black and white images of one band or a color image composed from several bands. Enlargements of parts of a scene or mosaics of several scenes may be necessary depending on the area of interest.
- b. Mapping - Satisfied by the spatial characteristics. The geometric accuracy of TM products is sufficient to permit detailed maps of surface features to be prepared.
- c. Surface Classification - Satisfied by the spectral characteristics. Multispectral analysis can be used to identify many different surface

properties (often referred to as themes when determined in this manner). Ground truth information is usually required to aid in the identification process.

- d. Change Detection/Monitoring - Satisfied by a combination of the temporal characteristics with either the spatial or the spectral characteristics. By comparing information extracted from data acquired on different dates, changes become evident. The comparison may require first performing multispectral analysis of the areas of interest and generating thematic maps.
- e. Mensuration - Satisfied by performing simple operations, often with hardware assistance, on the results of any of the previous three categories. Since Landsat data are computer compatible, they can be used to generate the required values in a straightforward manner.

All of the 41 specific applications/techniques given in the Murphy memo are not suited to the use of Landsat data, although Landsat can often provide related information. The 30m TM resolution obviously restricts its use in some cases, and the TM spectral bands may not always be sufficient for a particular situation. As an example, with MSS data it has proven very difficult to distinguish various forest components in some regions of South Carolina.

2.4 APPLICATION SCENARIOS

To utilize the information contained in the TM data most effectively requires a variety of techniques from fairly simple radiometric enhancements, which permit

an observer to identify geologic structures, to sophisticated data processing algorithms to differentiate between similar agricultural crops. To illustrate the utility of TM data, and to give an indication of the data processing requirements, several typical project scenarios are given. In each case a complete scenario is presented, to help indicate the role Landsat data can fill in overall COE activities.

2.4.1 DATA PROCESSING SCENARIOS

Processing scenarios were generated for a typical activity/application for the following categories:

- a. Hydrology/hydraulics (drainage basin mapping)
- b. Geologic studies (structural mapping)
- c. Land use mapping (changes/change detection)
- d. Coastal studies/water penetration and shoaling).

The synoptics/overviews and other categories were not described via a processing scenario because of their greater internal diversity and the limited use of computer processing for performing many of their activities/applications.

Table 2-5 summarizes several of the processing characteristics of the activity/application scenarios. The individual scenario processing flows will be discussed below:

2.4.1.1 Land Use Change Mapping

Figure 2-1 depicts a typical data processing flow for land use change detection and mapping utilizing TM data. Thematic mapper data is initially preprocessed

Table 2-5. Overview of Data Processing Requirements for Four COE Activities/Applications

	Land Use Change Mapping	Geologic Structural Mapping	Drainage Basin Mapping	Coastal Water Penetration & Shoaling
Number of Dates (per area of interest)	2	1	2	1
Number of TM Bands	4	7	4	4
Portion of TM Scene Analyzed	1/4	1	1/4	1/4 (3X)*
Input Frequency/ Session	10	10	8	10
Bulk Runs/ Session	3	3	1	1/4
Total Number of Sessions (per area of interest)	5	7	8	12
Total Number of Bulk Runs (per area of interest)	15	21	8	3

*Although not more than 1/4 of a scene would need to be analyzed from each scene, this activity/application area of interest is likely to extend across three scenes.

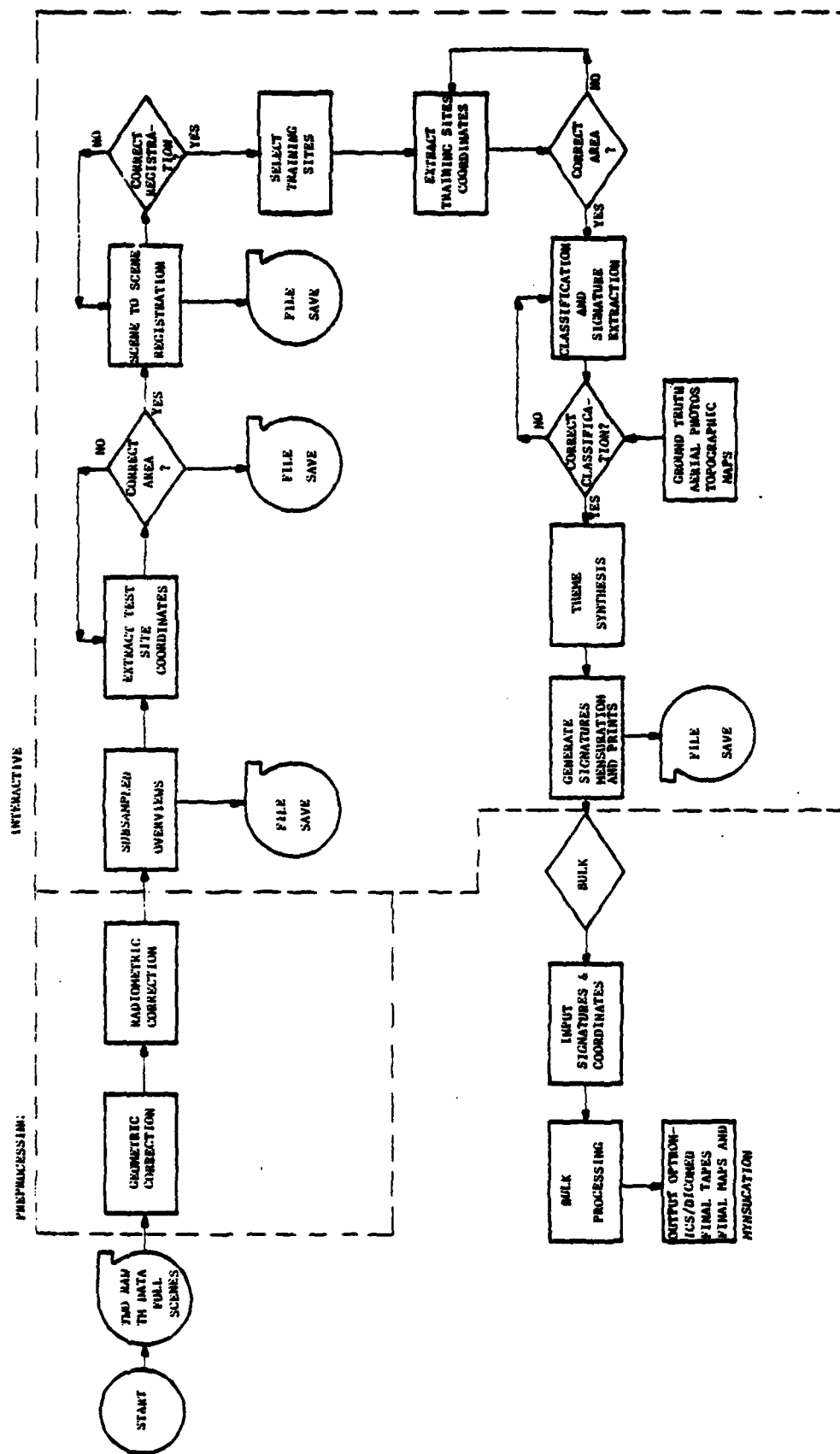


Figure 2-1. Landuse Mapping - Change Detection Data Processing Flow

for radiometric and geometric corrections because of the need to register results to existing maps and produce products attaining national map accuracy standards. Following preprocessing, a 512 x 512 pixel display overview of the scene is used to identify and locate the area of interest. Its coordinates are extracted, entered into the system, and the area of interest displayed as a full 512 by 512 pixel image. (Note: In a few cases, the area of interest may be the full Landsat scene thus making this step unnecessary.) The next step, registration of the data for which change is to be assessed, is central to the land use change scenario. The exact same area needs to be classified for both dates before class differences (visual and or area statistics) between the dates can be determined.

Sites representative of total area of interest are then selected and used to develop signatures (individual band upper and lower bound values) for each land use class for each date. After signature extraction is complete, screen level (512 x 512 pixels; approx 6 x 6 mi. areas) outputs such as alphanumeric printouts and theme prints are generated for verification of classification results against existing maps, photos, etc. Classification results of one date are then compared with those of the other date or a class by class basis and degree of change assessed. Training site(s) results are used for bulk classification of any area of interest greater than 512 x 512 Landsat pixels. Final output products include scaled thematic maps, binary prints of individual themes, photographic products, and tape files containing all scenes and the final classification and change detection results.

It should further be noted that the change detection concept is one that is applicable to other activities/applications. In fact, many types of multitemporal examination of the same area are oriented toward comparing the results of analysis of one date versus those of another even though the two sets of results are not generated simultaneously as described in this scenario.

2.4.1.2 Geologic Structural Mapping

Figure 2-2 presents a typical data processing flow for geologic structural mapping. In addition to geometric and radiometric correction, debanding is a necessary preprocessing function for geologic structure analysis. This is because the Landsat data analysis process for this activity/application is strictly visual interpretation dependent and data quality impediments such as drop out lines could result in interpretation errors. Photographic products, both black and white and color, will be output by the processing system for additional non-processing system associated analysis. These products will be generated both as preprocessing and interactive analysis (enhancement) outputs. No classification will be performed. Digital enhancement techniques to be used for photographic product generation will be:

- a. Edge enhancement
- b. Ratio-stretch
- c. Contrast-stretch
- d. Principle components.

Selected enhanced products generated via these techniques together with the unenhanced products selected will be output at one or more scales and used for

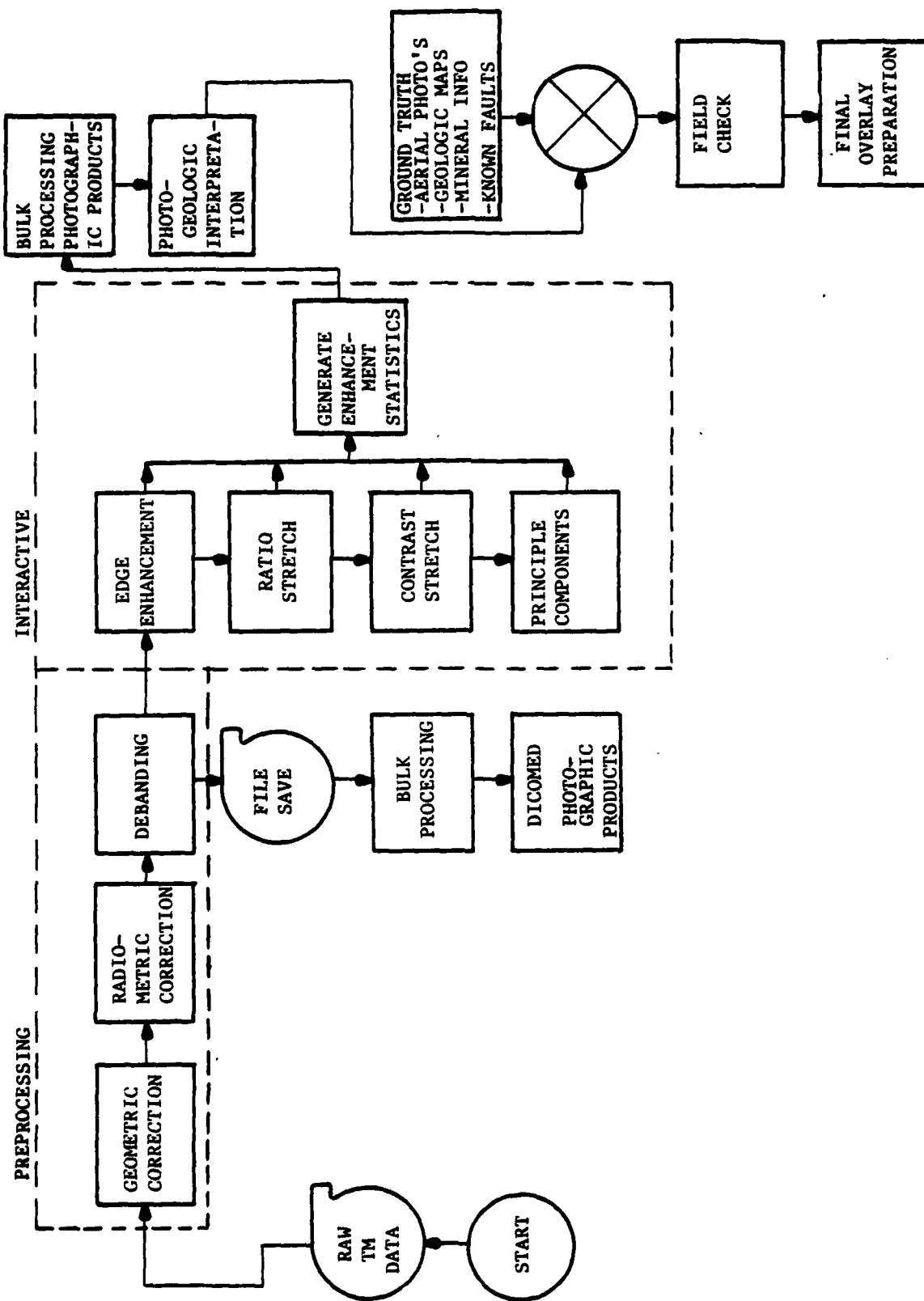


Figure 2-2. Geologic Studies - Structural Mapping Data Processing Flow

preparation of handdrawn overlays. Photogeologic interpretation results will be compared with any available ground truth and selected field checks made (as required) to verify the findings.

2.4.1.3 Drainage Basin Mapping

Figure 2-3 outlines a typical data processing flow for hydrology/hydraulics - the specific activity/application illustrated being drainage basin mapping. From an overview perspective, it should be noted that this scenario is more similar to land use change mapping than it is to geologic structured mapping in that classification rather than enhancement preparation is involved. However, it is different from land use change mapping in that different dates of Landsat data are not registered to each and change detection analysis is not performed.

Preprocessing consists of radiometric and geometric corrections since intermediate products will be used as overlays for existing USGS 7 1/2 minute topographic maps for drainage basin boundary delineation and classification class accuracy assessment. Initially the subsampled full scene will be examined to locate the area of interest. This area will be input into the system so that the drainage basin boundary and any grid data can be registered to the scene via an auxiliary scanner or digitizer. Once correct registration has been achieved, training sites are selected to be used for classification. The classification results are then compared to existing ground truth for verification and thematic maps generated to overlay the classes to aerial photographs or existing maps for final classification verification. This is an iterative process and new training sites may need to be selected or signature limits modified. The

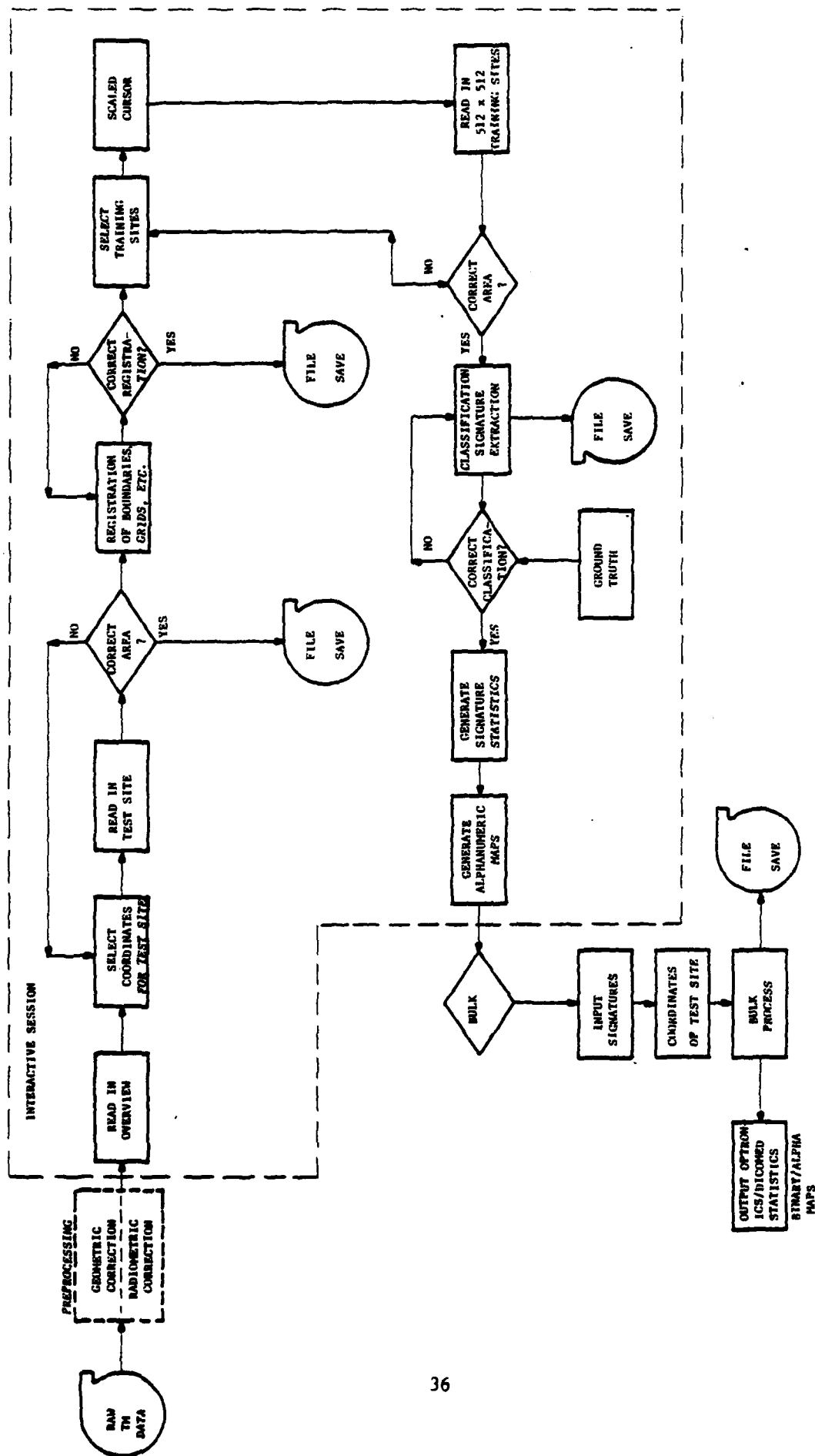


Figure 2-3. Hydrology/Hydraulics - Drainage Basin Mapping Data Processing Flow

signature limits and the drainage basic outline information are then input for bulk classification of the entire area of interest. Bulk run outputs consist of photographic products, area of classes, and thematic maps.

It should be noted that although a single date may be sufficient to satisfy drainage basin information requirements, there is likely to be a need for conducting a two date analysis - one during the moist, high water level portion of the year and one during the drier, lower water level portion of the year. Data for each of the selected dates would be analyzed separately as per the above discussion, change detection analysis per se would not normally be performed.

2.4.1.4 Coastal Penetration and Shoaling

Figure 2-4 delineates a typical data processing flow for coastal studies - the specific activity/application illustrated being water penetration and shoaling. The major analysis technique again involves classification, however, the basic facet that makes this scenario different from land use change mapping and drainage basin mapping is the fact that wall to wall (rather than training site selected) interactive classification needs to be performed. This requirement is necessitated by the fact that in a coastal studies environment signatures are at best limitedly extendible and thus no training site(s) representative of the entire area of interest can be readily selected.

The only preprocessing function noted in the processing flow, is geometric correction although radiometric correction would also frequently be advantageous even though single date analysis is performed. Again the area of interest is

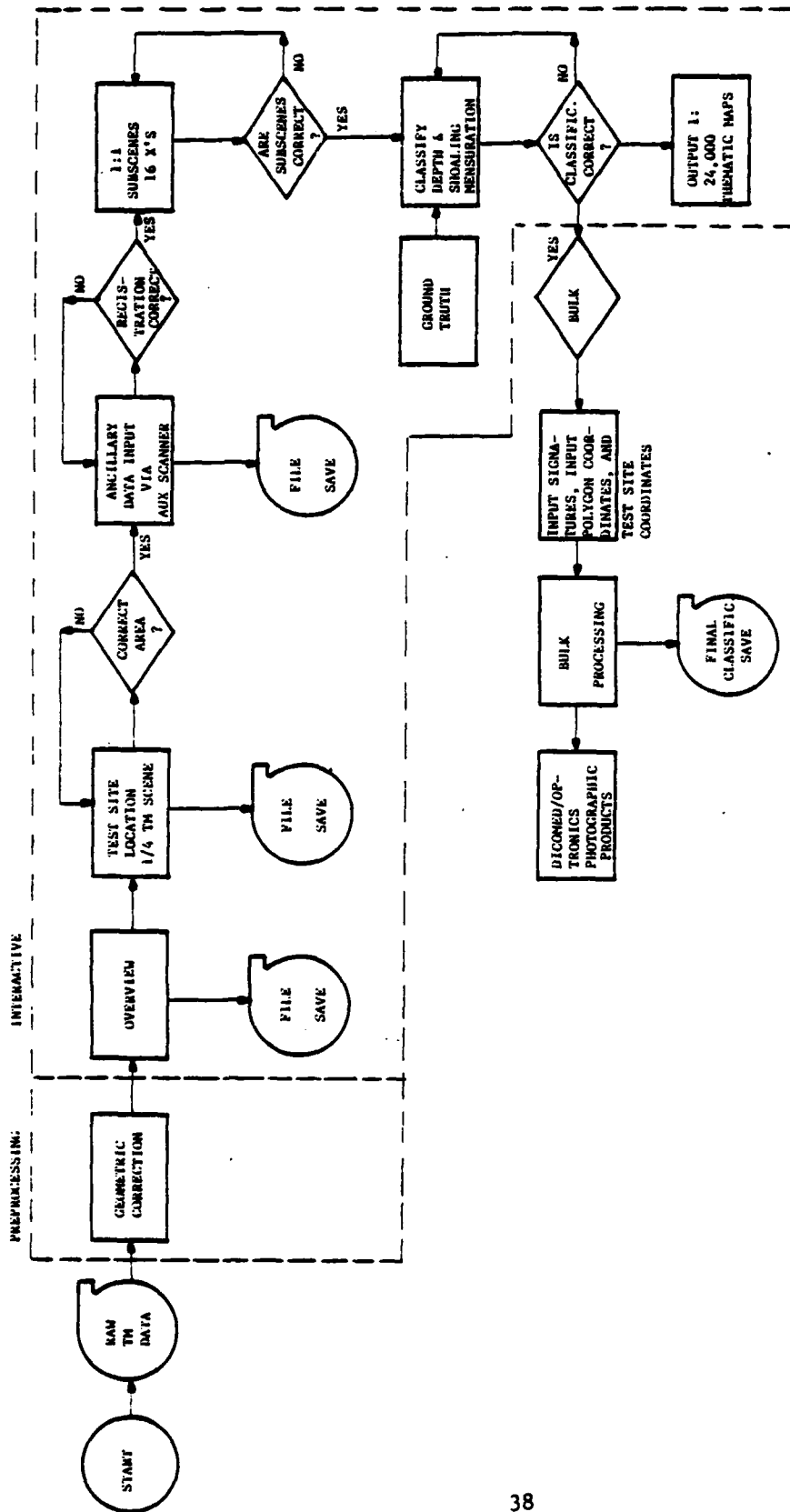


Figure 2-4. Coastal Studies - Water Penetration/Shoaling Data Processing Flow

selected from examination of the subsampled overview. Ancillary data (depth data, etc.) is input via an auxillary scanner and registered. Then the individual 1:1 subscenes are selected and classified. Following sufficient individual subscene analysis, iterations as dictated by whatever ground truth might be available, results are input into the bulk processor and products generated for the total area of interest. Final output products include photographic products, area of classes, and thematic maps.

2.1.1.5 Processing Function Time Requirements

A breakdown of the estimated time requirements for each of the processing functions appears in Table 2-6. Total interactive time for most functions performed during a processing session equals 1.5 hours. This does not account for iterations for scene inputs, misregistration of ancillary data, and misclassification and subsequent need to reclassify a single or multiple class(es). This, coupled with the fact that an operator can only remain productive for about two continuous hours has led to the assumption that a typical processing session will be approximately two hours in duration, and will result in processing of a single 512 x 512 pixel request.

Table 2-6. Functional Time Requirements

For Interactive Analysis of a 512 x 512 pixel Image Segment.

INTERACTIVE PROCESSING	TIME REQUIRED (MINUTES)
Full Scene	15.0
Test Site Location	5.0
Scaled Cursor	0.3
1/4 Scene	5.0
Training Site Location (512 x 512)	2.0
Scaled Cursor	
Auxillary Data Registration*	10.0
File Save to tape	2.0
Training Site Input	3.0
Scene to Scene Registration	20.0
Classification	
I-D training	0.75
Trim Histograms	5.0
2-D Projection	5.0
Data Space Partitioning	30.0
Theme Synthesis	10.0
<u>Output</u>	
Thematic Maps/Mensuration	4.0
Binary Theme Prints	0.5/theme
File Save	2.0
<u>Enhancements</u>	
Contrast Stretch	20.0
Edge Enhancement	40.0
Band Ratio	15.0/Ratio
Full Scene Film Production	30.0

* The auxillary data registration referred to here details the time for registration via auxillary scanner. A second method to input boundaries is to digitize vertices from baseline maps. The process is manual and required 3-5 minutes/topographic map.

2.5 INFORMATION MANAGEMENT

To integrate TM usage into COE activities requires, at the minimum, a data acquisition system. This could be as primitive as individual orders to the EDC in Sioux Falls, South Dakota, or it could be a complete COE interface with the Landsat-D data distribution system. In this study it is assumed that some version of the latter method will be used. In that case the COE will require its own archiving and retrieving system for TM data.

From the scenarios presented in the previous section, it is evident that Landsat data is normally used in conjunction with other information. It would be very useful for the COE to have an information management system that contained references to all available information (both within and external to the COE), such as its type, the geographic area covered, its age and accuracy, projects on which it was used, etc. Some of the types of data that are clearly relevant for COE projects are:

- a. Maps - basic USGS, with locations and elevations
- b. Special Maps - geologic structure, flood plains, vegetation, etc.
- c. Ground Truth - water flow rates, results of on-site inspections, plant types and vigor, survey points, etc.
- d. Aircraft - various instruments with a variety of spectral bands, high/low altitude flights, etc.
- e. Other Satellites - HCMH, TIROS, etc.
- f. Climatic - average rainfall, temperatures, etc.
- g. Documents.

One obvious way to catalog these entries would be by data type, with various descriptions as indicated above. Another useful entry into a complete information management system would be information about previous projects, including those performed by other government departments and agencies.

If such a data base were developed it would be essential to provide easy access to the desired information. One way to extract the contents would be by geographic area. A typical inquiry might start by querying the system for similar projects, perhaps restricting the search to recently completed projects, of a certain aerial extent, with a similar physical location (large river valley, mountainous region, etc.). Hopefully, several relevant projects would be located. The approach used and the input information utilized for each project would be extracted for future reference. Next the geographic coordinates of the current project area would be entered. Finally, the data base would be queried to ascertain whether or nor the desired information existed. Beyond this point there are many alternatives that could be examined depending on the details of the project.

2.6 DATA PROCESSING REQUIREMENTS

In the predecessor to this study an estimate was made of the potential yearly COE TM scene requirements in the 1981-82 time frame. Table 2-7 shows the result after comments from each district were incorporated. Most of the changes in the original estimates were minor. The numbers represent equivalent full TM scenes/year.

Table 2-7. TM Scene Requirements (No Cloud Adjustment)

PROGRAMS		1	2		3	4	5	6	7	8	9
DISTRICTS	DIVISIONS	STUDIES	SPECIAL CONTINUING AUTHORITIES		DISASTER ASSIST		FLOOD PLAIN MGMT. SERVICES	ENVIRONMENTAL STUDIES	NAT'L DAM SAFETY PROGRAM	REGULA-TORY PERMIT PROGRAM	R&D LAB
			SMALL FLOOD PROJECTS	NAVI-GATION	SHORE-LINE ETC.	DAMAGE ASSESS.		HABITATS WATER QUALITY			
NEW ENGLAND	NEW ENGLAND	6	10	5	3	5	4.5	10	8	4	8
NEW YORK, NY	NORTH ATLANTIC				2						
PHILADELPHIA, PA					2						
BALTIMORE, MD					3						8
NORFOLK, VA					3						
WILMINGTON, NC	NORTH ATLANTIC				4						
CHARLESTON, SC					4						
SAVANNAH, GA		5			4						
JACKSONVILLE, FLA		10			4						
MOBILE, ALA		10			4					10	
NEW ORLEANS, LA	LOWER MISSISSIPPI VALLEY		10		4					4	
VICKSBURG, MISS		10	2	2							8
MEMPHIS, TENN			10	5					15		
ST. LOUIS, MO				5							
GALVESTON, TEX	SOUTHWESTERN			5	4						
PORT WORTH, TEX						5					
ALBUQUERQUE, NM						10					
LITTLE ROCK, ARK				3		5					
TULSA, OKLA				3		5					

Table 2-7. TM Scene Requirements (No Cloud Adjustment) (cont'd)

PROGRAMS		1	2		3		4	5	6		7	8	9
DISTRICTS	DIVISIONS	STUDIES	SPECIAL CONTINUING AUTHORITIES			DISASTER ASSIST		FLOOD PLAIN MGMT. SERVICES	URBAN STUDIES	ENVIRONMENTAL STUDIES		NAT'L DAM SAFETY PROGRAM	REGULATORY PERMIT PROGRAM
			SMALL FLOOD PROJECTS	NAVL-GATION	SHORE-LINE ETC.	DAMAGE ASSESS.	FLOOD PREDICTIONS (SHOW)			HABITATS WATER QUALITY	EIS		
KANSAS CITY, MO OMAHA, NEBR	MISSOURI RIVER	6	10	5		5	90	2.5	.5	10		8	4
NASHVILLE, TN													
LOUISVILLE, KY	OHIO RIVER												
HUNTINGTON, W VA													
PITTSBURGH, PA													
ST. PAUL, MINN	NORTH CENTRAL												
ROCK ISLAND, ILL							90						
CHICAGO, ILL					2		90						
DETROIT, MICH					2		45						8
BUFFALO, NY							45						
LOS ANGELES, CA	SOUTH PACIFIC				3		45						
SAN FRANCISCO, CA													
SACRAMENTO, CA							90						8
PORTLAND, OR		10					90						
SEATTLE, WASH	NORTH PACIFIC	10	5	4		4	90			5		10	10
WALLA WALLA, WASH		6	10	5		5	90			10		8	4
ALASKA		6	10	5		5	90			10		8	4
PACIFIC OCEAN		11	8	10	8	5		5	5	10		2	17
		245	360	182	75	194	1035	98	23	370		307	177

Two types of requirements are found in Table 2-8, one for near real-time, perishable data (flood prediction program, regulatory permit program and damage assessment) and another for non-real-time efforts with non-perishable products. Table 2-8 shows the yearly and average daily scene requirements for these two categories for each COE division. These numbers will be used later to size data processing systems and communications links. The totals should be considered only as a first approximation to the actual TM data requirements in a fully operational environment.

The scene processing requirements discussed above are all project related. An additional requirement exists to process data for an archive of TM scenes that will be available when needed for individual projects. It appears that an archive containing five to six acquisitions/year for each ground area would be adequate. This would normally include seasonal coverage and also allow any special coverage requirements for particular scenes to be satisfied. For areas in Alaska only two acquisitions/year should be adequate for archive purposes. Table 2-9 indicates the total yearly processing requirements to maintain an archive of this size. (Cloud cover considerations will be addressed later.) On a division basis (Alaska and South Pacific excluded) a more detailed breakdown is given in Table 2-10. The number of coverage cycles/year for each division was based on an analysis of the peculiar requirements for this division. The number of scenes in a division is based on Landsat 1, 2, 3 coverage patterns and sums to more than 450 because of the large number of scenes that are on the boundary between several divisions. However, the yearly totals in Table 2-9 and Table 2-10 are in good agreement.

Table 2-8. Estimated TM Scene Processing Requirements

DIVISION	NON-PERISHABLE DATA	PERISHABLE DATA+
New England	53 (0.2)*	54 (0.6)**
North Atlantic	186 (0.6)	36
South Atlantic	228 (0.9)	51
Lower Mississippi Valley	231 (0.9)	36
Southwestern	205 (0.8)	50
Missouri River	84 (0.3)	198 (2.3)
Ohio River	166 (0.7)	36
North Central	224 (0.9)	360 (3.9)
South Pacific	143 (0.6)	162 (1.7)
North Pacific	237 (0.9)	401 (4.5)
Pacific Ocean	59 (0.2)	22
	<hr/>	<hr/>
TOTAL	1,816 (7.3)	1,406 (12.9)

+ For flood prediction program, regulatory permit program, and damage assessment

* Yearly total followed by daily average in parenthesis (based on 250 working days/year)

** Yearly total followed by daily average for flood prediction only. The flood prediction data is assumed to be acquired in 16 weeks (80 working days).

Note: Numbers may not be 100% accurate; they must be checked.

Table 2-9. Estimated TM Scene Archive Requirements

	YEARLY	DAILY AVERAGE*
48 States & Hawaii	2,700	10.8
(450 scenes * 6 acquisitions)		
Alaska	500	2.0
(250 scenes * 2 acquisitions)		
	<hr/>	<hr/>
TOTAL	3,200	12.8

*Assuming 250 working days/year

Table 2-10. Scene Archive Requirements by Division

	COVERAGE	NUMBER OF SCENES IN DIVISION	SCENES PER YEAR
	CYCLES/YEAR		
New England	6	15	90
North Atlantic	7	23	161
South Atlantic	6	47	282
Lower Mississippi	7	23	161
Southwestern	4	84	336
Missouri River	5	84	420
Ohio River	5	33	165
North Central	6	72	432
South Pacific	5	85	425
North Pacific*	6	54	324
TOTAL			2,796

*Excluding Alaska

SECTION 3

IMAGE ANALYSIS CAPABILITIES REQUIREMENTS

3.1 INTRODUCTION

This section discusses the capabilities of an Image Analysis System (IAS) in terms of analysis and data and display manipulations. Distinctions are made between input/output, display, and spectral, and spatial analysis requirements, and indications of the practicality of batch vs. interactive operation are discussed.

These capabilities, implemented in hardware components vs. hardware/software subsystems, are the key to the utility of the system for image analysis purposes. It should be recognized that the objective in design of such a system is the provision of a capability that aids an operator in interpreting data by enhancing radiometric, spectral and spatial characteristics so that they are readily identifiable by the human eye. In relatively few areas is it possible to provide completely automatic analysis and mensuration capability without some degree of manual supervision. As a consequence of this, a significant portion of the capabilities required in an Image Analysis System are related to data manipulations for display purposes, and should be implemented in a manner that provides rapid response to operator actions.

Another large portion of the capabilities required is in the area of data input/output. Data provided to the system may be in many forms (film, high density tape, CCT tabular listings, maps, etc.) and output data may be required in a similarly diverse set of products. In addition, internal data transfers

between mass storage devices and core resident or display refresh storage will be required. A further complication of the data input process is the Landsat-D scenario, discussed in Section 1, which results in data packing on tape that is highly efficient from a production tape generation aspect. The format used creates significant difficulties in analysis since it requires that the user Image Analysis System search through the HDT to identify regions of interest for analysis purposes.

It should be noted that the capabilities listing that follows is presented as a design guide only so that a number of capabilities, oriented to specific COE requirements, can be selected.

3.2 DATA INPUT/OUTPUT

Data I/O functions provide for the capability of the system to ingest data from a variety of sources, such as high density tapes, computer compatible tapes, hardcopy (maps or film) products or by input of tabular descriptors. Similarly, a wide range of output products may have to be generated for different user applications. The options available for data I/O processing are discussed below.

HDT Read - Provides the ability to search for specific image data from a Landsat-D high density tape, in either HDT-A or HDT-P form, and in BIL or BSQ format, and input to the IAS for processing. This operation will normally be conducted in batch mode after manual initiation.

CCT Read - Provides the ability to read image data from CCT into the IAS. This operation will normally be conducted in batch mode.

Film Input - Provides a capability to input data as monochrome or color film images, and to digitize and process as digital scene data.

Analog Tape Input - Many airborne sensors generate data on analog tapes. This capability will permit the input of such data in digital form for processing.

Map Digitization - The X-Y coordination of features identified from maps can be input using this process.

Tabular Data Input - This function provides the capability for input of tabular and descriptive data that may be required for correlation to image data for analysis.

Film Product Generation - Many output products use a photographic process as a base. Film product generation uses image recording systems to generate both color separation and full color negatives. These can then be used to generate color prints for display purposes, or for the generation of color lithographic products. Map overlays may also be generated photographically, especially in cases where color overlays are required.

Map Generation - Precision maps at standard scales may be required, both for overlays and as single end items.

CCT Products - Major programs that use Landsat and other image data analysis methods as a part of an overall analytical process may require results to be generated as CCTs in a form suitable for entry into an independent data base or information management system.

Hardcopy Products - Many interim products or preliminary results may be generated as prints or plotter outputs, using standard line printer or electrostatic or drum plotter peripherals.

3.3 DATA PREPARATION AND DISPLAY CONTROL

Data preparation functions are those that permit an operator to review data memory contents, load or change memory contents, edit data, correlate ancillary data, and change data formats. These functions are described below.

Refresh Memory Load - Most functions that are performed on a single spectral channel, or that are display-oriented, are driven by spectral data from a refresh memory. This function provides the ability to load the refresh memory from a mass storage device.

Reduced Resolution Review - In order to facilitate data editing, a review of a larger area containing the site of interest is often desirable. This function provides an averaging of pixels to permit large area images to fit on the limited size display.

Scroll Image - An alternative review method is the use of scrolling, where the displayed area is selected variably throughout the larger area.

Image Zoom - In some cases it is required that a small image be expanded in size to fit the full display area (or some specific portion of the full display). The zoom function provides this magnification.

Time Lapse - For some purposes it is desirable to show changes taking place through analysis of images taken at successive times. A time lapse sequence permits such a display.

Flicker Mode Display - The ability to alternate images of the same scene on the display screen can be useful for the detection of changes from some baseline. This mode is particularly useful for band-to-band registration of images.

Cursor Control - Provides the operator with a means of selecting specific regions of the displayed image for further analysis or for use as spectral control data or training sites. Cursors can be provided as square, rectangular or polygonal in shape, and may be re-entrant.

Data Edit - The data edit function permits the operator to define scan lines and pixel designators that describe the borders of the image of the area of interest. This image area, which may be greater or less than a single Landsat scene, will then be stored in a local mass storage device (such as a disk system). A second editing function permits selection of the specific image area to be displayed.

Data Merge - Provides the ability to correlate ancillary data to Landsat imagery.

Georeference Data Correlation - Provides a special case of data merging where a specific georeference coordinate system is used as the basis for merging data.

Split Screen Display - Provides the ability to display multiple sub-images of the same or different scenes on the display screen.

3.4 DATA CORRECTION

Data correction requirements can be classified into two categories, radiometric and geometric. Special cases of geometric correction are such items as image-to-image registration (for both multitemporal images and for multisensor images) and image registration to a map reference grid.

Radiometric Correction - Provides the capability for correcting raw image data for radiometric distortions caused by the imaging sensor, by the use of internal calibration sources or by the use of scene dependent features.

Geometric Correction - Provides the capability to correct radiometrically corrected image data for geometric distortions due to internal sensor effect and the effect of platform motion. Geometric corrections are typically processed in two stages, first by computing the magnitude of the correction to be applied and then by actually applying the corrections. These processes do not necessarily need to be performed in successive operations, thus geometric corrections can be computed prior to a processing stage, and the correction applied following the processing. The corrections applied may be used to generate images based on different map projections.

Image Registration - Provides the ability to register, on a pixel-by-pixel basis, images taken of the same scene by the same sensors at different times, or by different sensors at the same time.

3.5 SINGLE BAND IMAGE ANALYSIS

Single band image analysis techniques provide procedures for analysis and

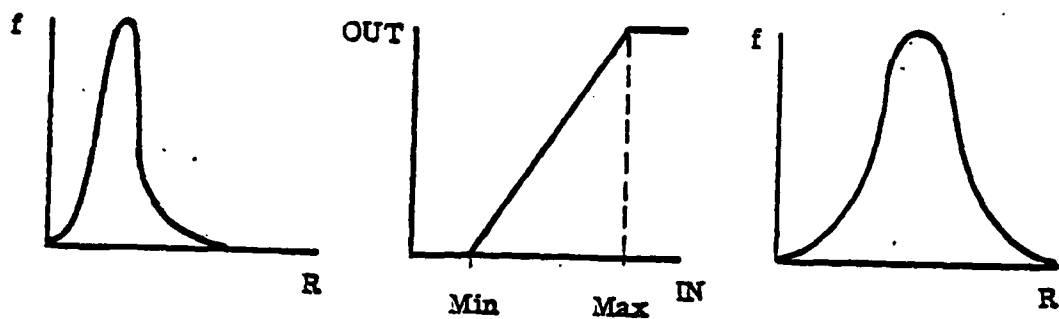
enhancement of monochrome data, such as would be provided by a single spectral band of a Landsat sensor. The single band designation does not preclude application of enhancements or analyses identically to all bands, but rather indicates the independence of the techniques from spectral characteristics.

Contrast Stretch - Contrast stretching is the application of a predictable transformation to signal amplitude so that the effective contrast between scene elements is change. Many transfer functions can be provided, based on linear (gain and offset), histogram equalization, piecewise linear fit transformations, and other analytic functions such as square root. Figure 3-1 shows the effects of these typical contrast stretch transformations on an input signal histogram. Contrast stretching may be used as a standalone analytical technique, possibly enhanced by various display options described below, or it may be used as a precursor to more complex spectral analysis methods, as described in paragraph 3.6.

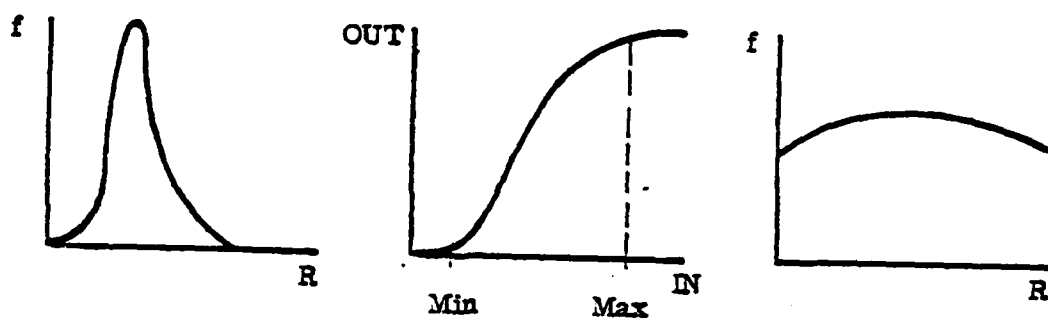
Density Slicing - The use of grey scale enhancement to emphasize the brightness differences between scene elements. In this technique, a limited set of discrete grey levels (usually 16) is used as an output, and the input data pixels are assigned a specific grey scale value according to their amplitude. This technique can be combined with contrast stretching to provide nonlinear enhancements.

Contour Generation - Provides the capability of generating iso-amplitude contours, either as an image overlay or as a standalone display.

LINEAR



HISTOGRAM EQUALIZATION



SQUARE ROOT

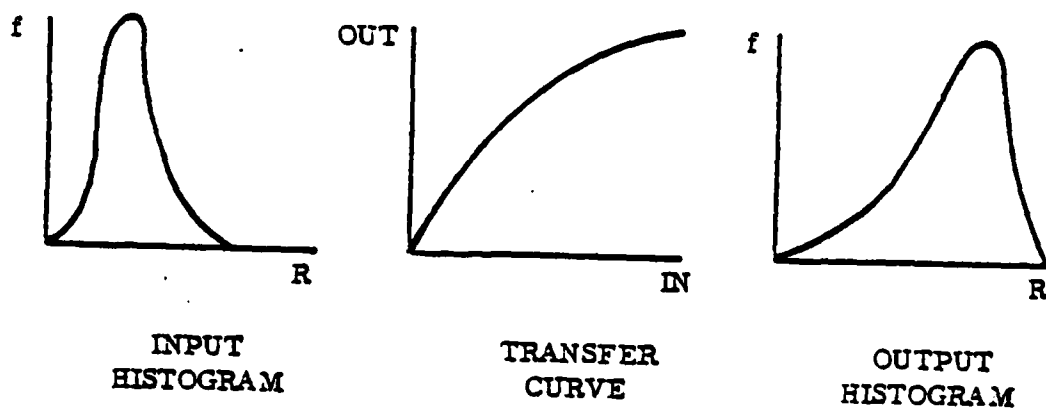


Figure 3-1. Contrast Stretch Algorithms

Spatial Filtering - An important attribute of an image is the difference in amplitude between adjacent pixels, which designates the "texture" of the scene from a radiometric point of view. In some cases, the identification of textural parameters is an aid to analysis, in others it is a hindrance. Spatial filtering techniques can be used to either enhance textural effects or suppress them, as required.

Edge Enhancement - Edge enhancement is a special case of spatial filtering designed to provide an improved definition of the edges of spatially distinct features.

3.6 SPECTRAL SIGNATURE ANALYSIS

As shown in Figure 3-2, a multispectral signature is simply the response of a given material at different wave lengths of electromagnetic radiation. Note that Landsat 3 provides the reflectance of light at two visible wavelengths (green and red) and three nonvisible wavelengths (reflective and thermal infrared). The reflectance curves are idealized representations of the real world; in actuality, materials are not "pure." The curves actually occupy some range of reflectance values of each wavelength.

The two-dimensional cluster plots of Figure 3-3 represent the data more realistically. Each of the clusters would be shown as a single point in an idealized representation. The problem then is to associate feature space regions with categories of interest. Signature analysis techniques exist to properly understand and characterize graphically and statistically the distribution of data clusters within feature space, as do classification

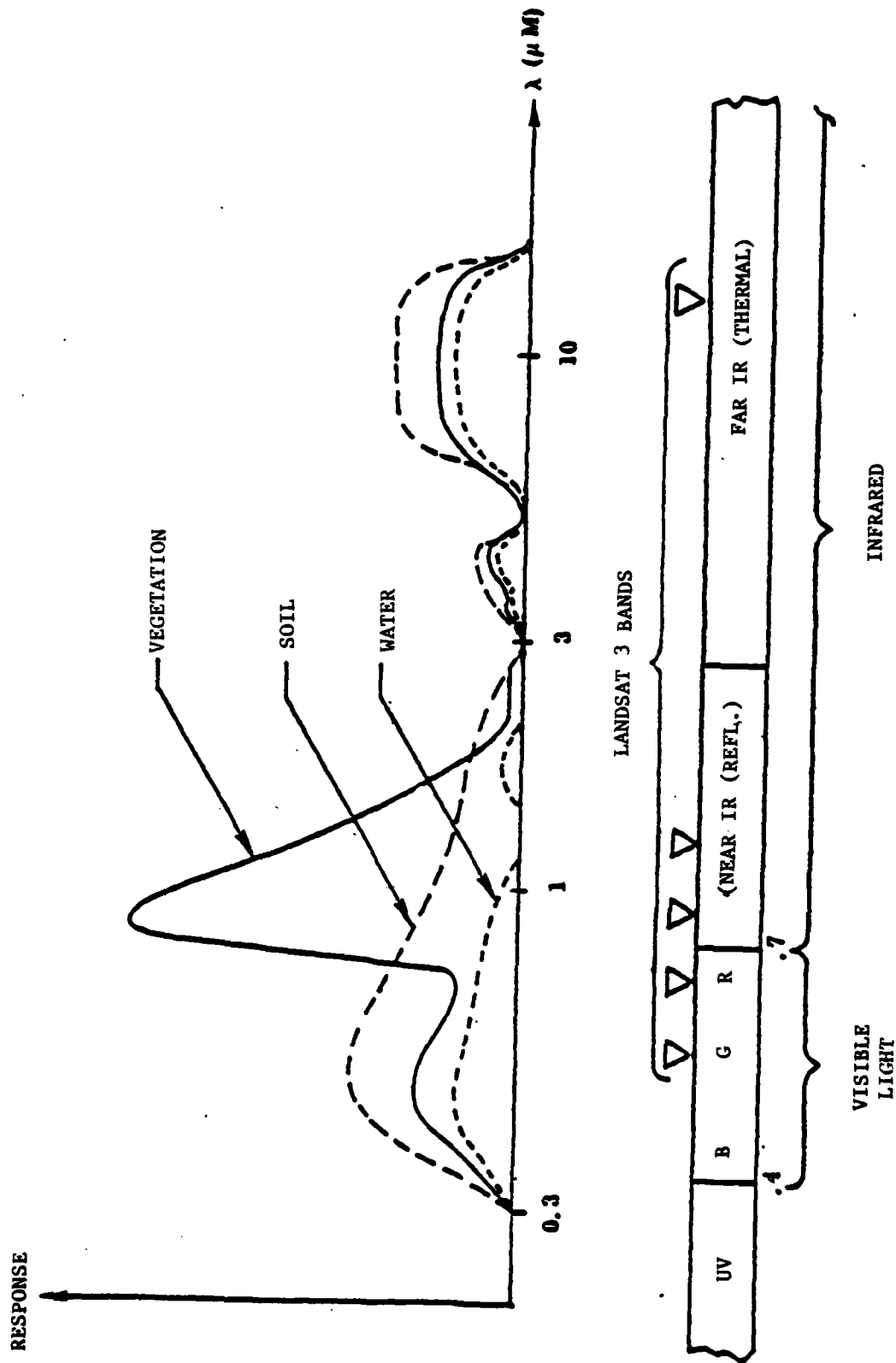


Figure 3-2. Typical Multispectral Signatures

techniques to actually perform the feature space partitioning and assignment of categories.

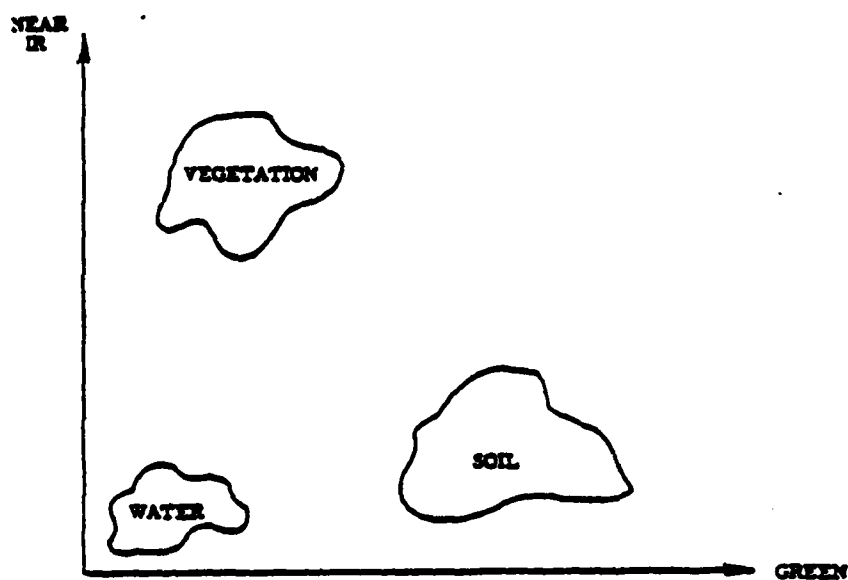


Figure 3-3. Two-Dimensional Cluster Plots

Spectral signature analysis techniques can be categorized into two classes. First, preprocessing functions may be performed on the data to correct for known spectral distortions, such as large removal, variable illumination effects, etc., or to enhance spectral differentiation by a rotation of the axes in feature (spectral) space.

The record class of techniques are those that use spectral signature characteristics as a means of grouping and identifying discrete pixels or areas of the image.

3.6.1 PREPROCESSING FUNCTIONS

The primary purpose of preprocessing functions is to transform the image observation space into a new feature space, more suitable for signature analysis and classification. The imagery is often visually enhanced in the process, helping the analyst to better understand the data, as well as supporting the analysis and classification processes themselves.

Two categories of radiometric functions can be provided:

- a. Mathematical combination of spectral amplitude
- b. Spectral rotations.

These affect the intensity levels of the pixels within a given scene or frame of data, but do not affect the geometry (i.e., pixel location).

Mathematical Combination of Amplitude - The most common mathematical process is ratioing, although summation of bands to create a new (wider) spectral band is sometimes used. Typical of ratioing functions are:

- a. Ratio of two channels
- b. Ratio of difference over sum of two channels
- c. Ratio of each channel to sum of all channels (normalization).

Mathematically:

$$\begin{array}{ll} \text{a.} & \frac{R_i}{R_j} \\ \text{b.} & \frac{R_i - R_j}{R_i + R_j} \\ \text{c.} & \frac{R_i}{\sum R_i} \end{array}$$

Where R_i = Response from channel i

The primary motivation for ratioing is to transform the raw image data (the observation space) into a feature space in which new signatures, less dependent on environmental, observational, and sensor conditions, can be extracted. Changes in the above conditions cause both multiplicative and additive factors to be introduced into the data. Table 3-1 tabulates the types and causes of various multiplicative and additive factors.

The ratioing of adjacent channels (a) tends to eliminate the common multiplicative factors (in the absence of significant additive factors). The other two ratioing techniques offer the additional capabilities of reducing additive effects (b), and of being computationally bounded (b) and (c).

A geometrical interpretation of ratio (c), normalization, is offered in Figure 3-4. A hypothetical material with good correlation between channels R_1 and R_2 is shown to be defined by three different clusters due to the variability of illumination conditions (sunlit through shadowed). Normalization would transform the signature to a straight line with slope -1 as shown. Note that magnitude, or intensity, has been eliminated. It could be said that a range of hues has been defined with common brightness.

Table 3-1. General Factors that Produce Signal Variations

Variable Factor	Causes and Dependencies	Type of Factor	
		Multiplicative	Additive
Illumination	Shadows, time of day, clouds, etc.	X	
Transmittance	Altitude, haze, aerosols, scan angle	X	
Reflectance	Scan angle, sun angle, species, maturity, vigor	X	
Atmospheric Backscatter	Altitude, haze, aerosols, sun angles		X
Sensor Gain	Different setups, different days	X	
Noise	System components		X (primarily)

The advantage to the user is that he need not identify training sets for each illumination condition; he need only locate one representative site of the correct hue. Also, dimensionality is reduced by one; a four-channel image such as Landsat is reduced to three, leaving room for additional imagery and/or reducing subsequent processing time.

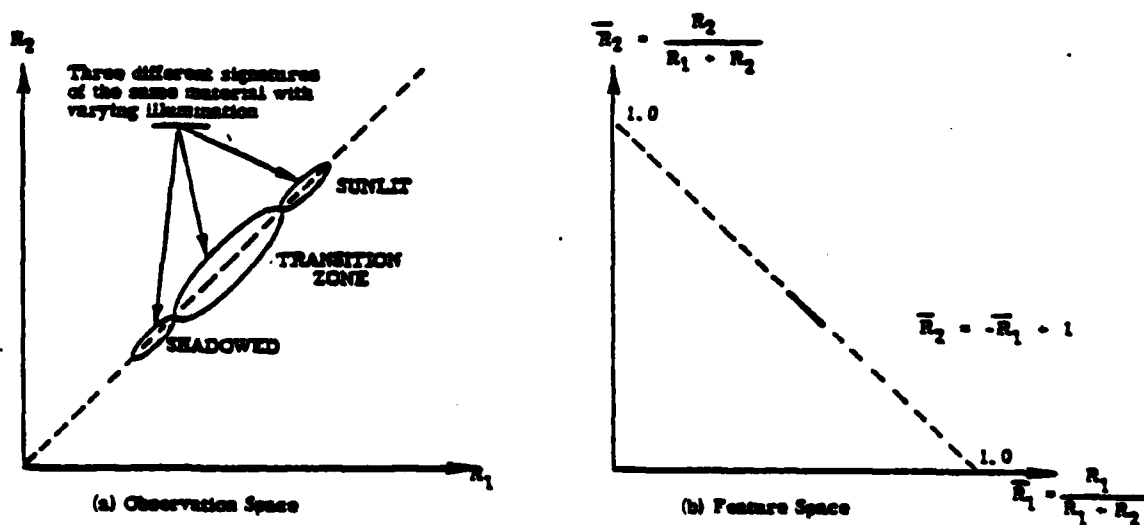


Figure 3-4. Normalization

Spectral Rotations - The rotation technique that is most often used has several characterizations in the literature: factor analysis, Karhunen-Loeve, and eigenvector analysis. Basically, these all refer to the same process. The covariance matrix is computed for a given training site, from which the eigenvalues and eigenvectors are computed. (The geometrical interpretation of eigenvectors is shown in Figure 3-17.) The eigenvectors define the direction of the major and minor axes, and the eigenvalues are a measure of the spread, or variance, of the data in each axis. The matrix of eigenvectors, properly scaled, is the rotation matrix.

Mathematically:

$$\underline{MR} + \underline{T}$$

Where

R = Response vector

T = Translation vector

M = Rotation matrix

There are several motivations to provide this transformation capability:

- a. Dimensionality reduction
- b. Visual enhancement
- c. Improved fit of the signature clusters by the single cell approximation.

A spectral rotation can result in a reduction in the number of channels required to describe a signature. The following geometric example is offered to

illustrate reduction from three channels to two: a round disk can be situated inside a cube such that regardless of which face of the cube the disk is viewed from, the disk appears to be elliptical in shape. Furthermore, the viewer is not able to determine whether the disk is a flat object or a solid object. However, by rotating the disk such that one edge is visible to the viewer on two faces, it becomes apparent that only two dimensions are required to describe it, as shown in Figure 3-5.

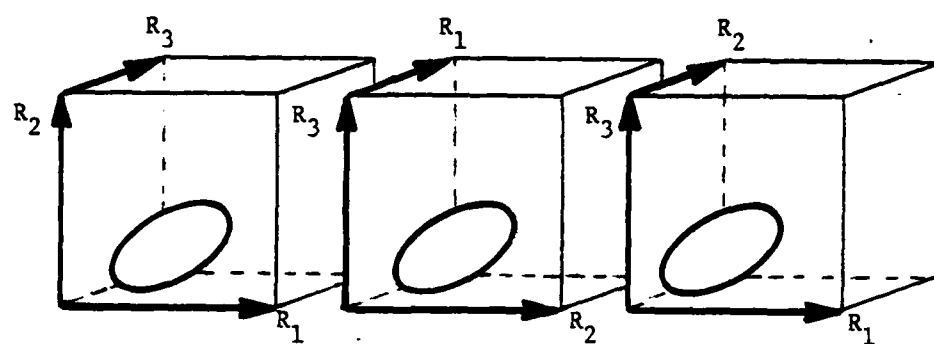
The analyst may manually specify any rotation matrix and/or translation vector, as well as the eigenvector rotation described earlier. For example, a matrix of positive and negative one's (along with an appropriate translation vector) may be defined to perform channel subtraction. The different image, when used with multitemporal imagery, is a useful change detection tool.

Since spectral rotation causes a color shift in the displayed image, the analyst may experiment with arbitrary routines until such time as features that are of interest are enhanced on the color CRT.

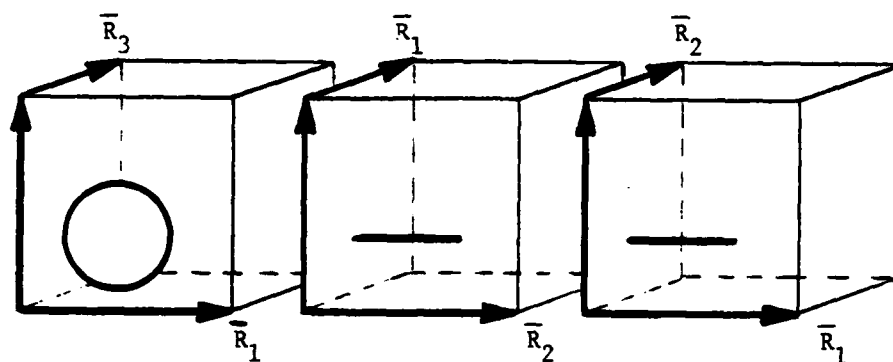
3.6.2 SIGNATURE ANALYSIS

A variety of signature analysis techniques are provided to support statistics acquisition, display and modification. Most require ground truth knowledge (i.e., known training sites) and are therefore supervised techniques; however, one nonsupervised approach - clustering - is also provided. Feature space regions may be analyzed in any of four ways (reference Figure 3-6):

- a. Nonparametric - single cell analysis
- b. Nonparametric - multicell analysis
- c. Parametric - Gaussian
- d. Parametric - Cluster

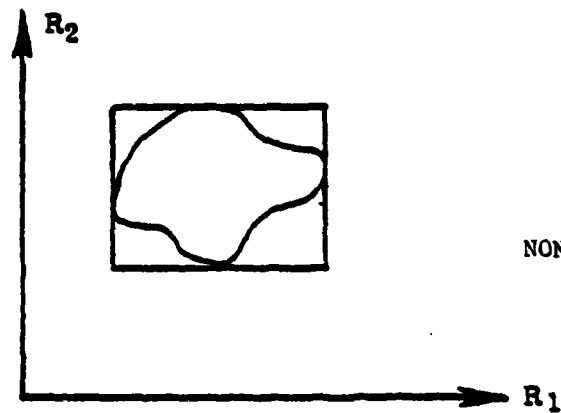


(a) BEFORE ROTATION

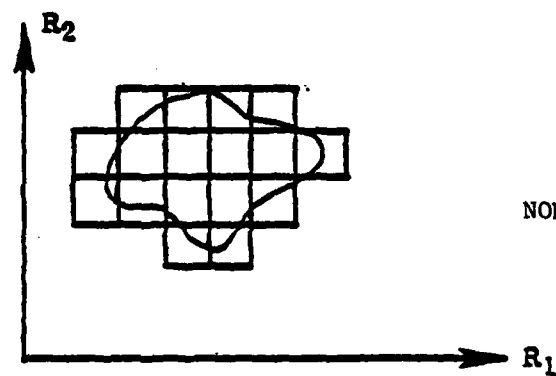


(b) AFTER ROTATION

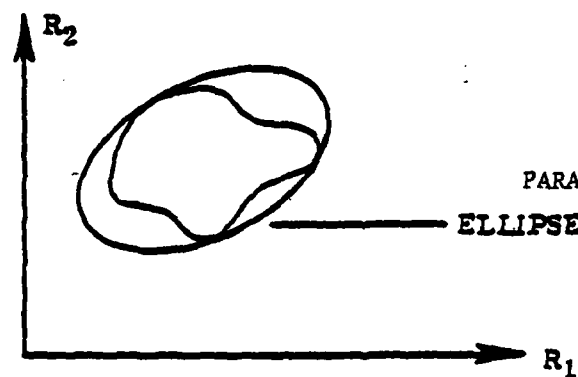
Figure 3-5. Spectral Rotation - Dimensionality Reduction



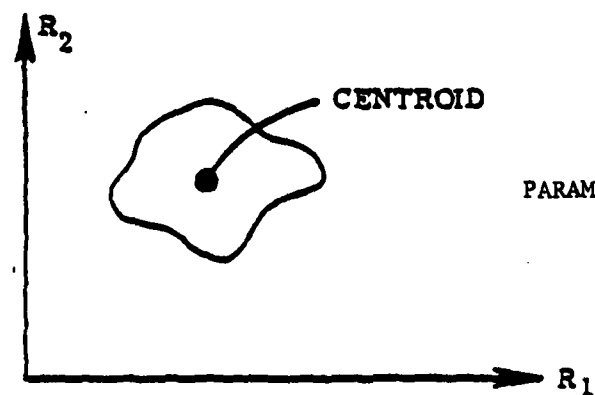
NONPARAMETRIC - SINGLE CELL ANALYSIS



NONPARAMETRIC - MULTICELL ANALYSIS



PARAMETRIC - GAUSSIAN ANALYSIS
ELLIPSE



PARAMETRIC - CLUSTER ANALYSIS

Figure 3-6. Signature Analysis Techniques

The nonparametric techniques are completely unbiased, in that distributions are measured. The single cell mode is a gross first approximation; however, experience has shown it to be quite useful in most applications. The multicell mode does a much better job of properly representing the actual distribution, but suffers from the penalty of requiring a large training sample to avoid a "sparse population" condition. Both nonparametric methods are limited to four dimensions.

The parametric techniques, on the other hand, introduce a bias in that the distribution shapes are predetermined. However, they have the advantages of requiring fewer training samples, and of extending to six dimensions. In addition, the clustering technique requires no a priori knowledge of training sites.

3.6.2.1 Nonparametric - Single Cell Analysis

Single cell signature analysis is diagrammed in Figure 3-7. The major steps are discussed below.

Training Site Selection

A training sample must be carefully selected; the analysis is only as good as the data processed. The cursor, previous classification results, a theme track, or artificially created data, or any Boolean combination of the above can be used to select the training site.

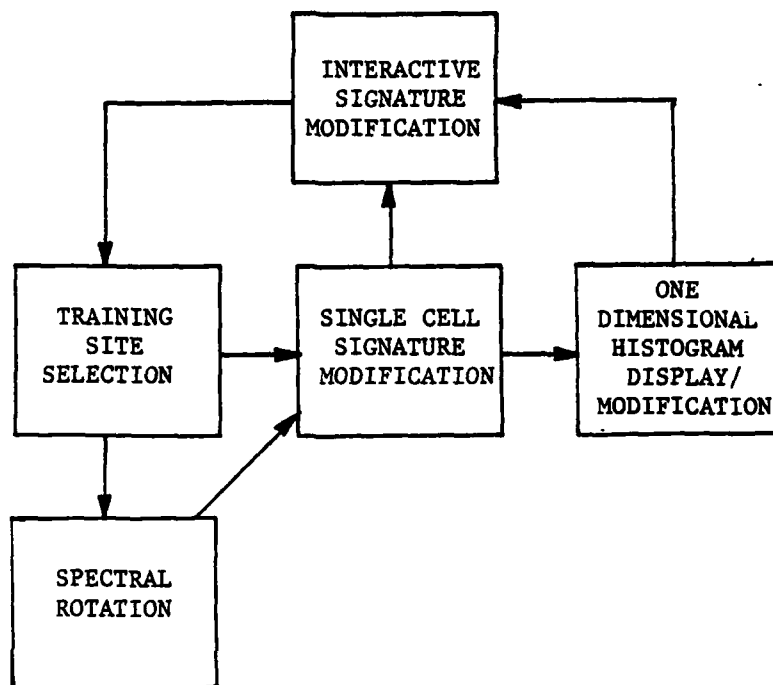


Figure 3-7. Single Cell Signature Analysis

Single Cell Signature Acquisition

A three dimensional single cell signature acquisition process is shown in Figure 3-8. Following identification of the training area, the system generates the three histograms independently for each of three wavelengths. Based on these distributions, and other user input parameters, the minimum and maximum reflectance values are determined. These limits one pair per wavelength, define a single cell, or parallelepiped, in spectral space; this is the first approximation to the true signature.

For some types of data, this approximation may suffice; for others, it may not. To illustrate, refer to Figure 3-9; this illustrates how signatures can overlap and cause misclassification when single cell approximations are applied. The overlap can be eliminated in several ways, assuming that the classes are separable (as shown in the illustration). They include the following:

- a. One dimensional histogram display/modification
- b. Interactive signature modification
- c. Spectral rotation
- d. Multicell analysis.

One Dimensional Histogram Display/Modification

The one dimensional histogram limits may be modified either before or after single cell signature acquisition (pre- or post-processing). In the former case, the limits are assigned such that the enclosed area of the 1-D histogram (i.e., cumulative distribution) meets an operator input percentage. For example, the user may initialize the acquisition process at ten percent above the minimum reflectance and ten percent below the maximum reflectance for a given channel, leaving 80 percent included within the limits.

In the post-processing mode, the user is able to manually position the upper and/or lower limits using a histogram display for reference. The alarmed pixels will respond to the changes, allowing the user to observe the effects of the spectral limit changes in the spatial domain (see Figure 3-10). Note that correctly classified areas can be deleted along with the undesirable areas.

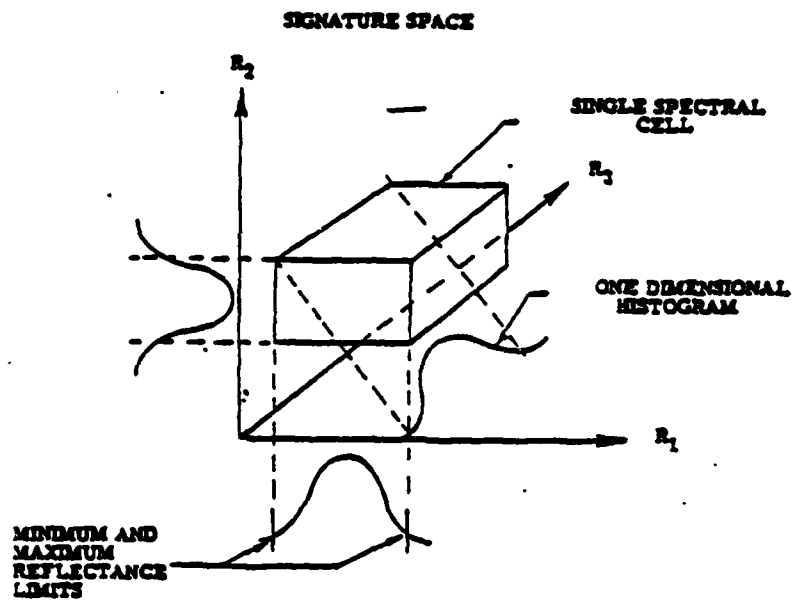


Figure 3-8. Single Cell Signature Acquisition

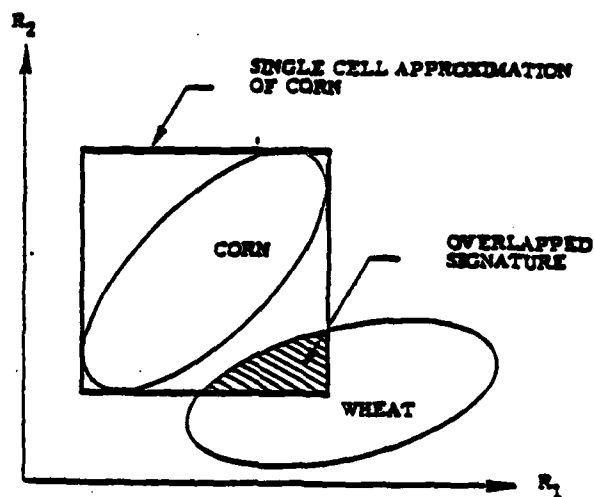


Figure 3-9. Single Cell Signature Overlap

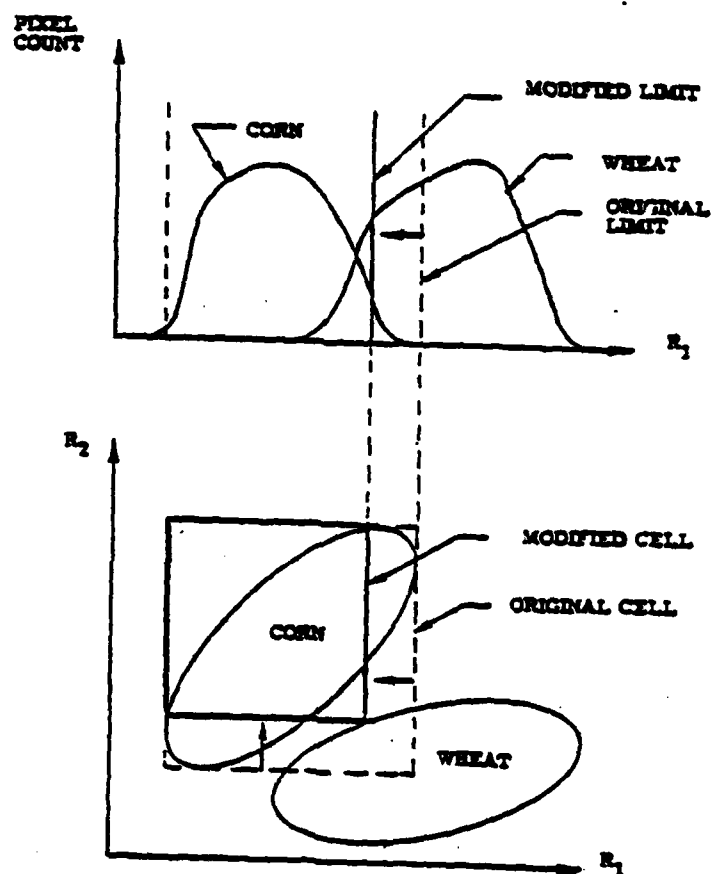


Figure 3-10. Histogram Limit Modification

Spectral Rotation*

The single cell approximation to signature clusters often contains much "empty space." This poor fit often causes signature overlap and thus misclassifications. One approach to resolving this overlap problem is to spectrally rotate the signature space axes such that the new axes are approximately orthogonal to the major and minor axes of the signature cluster. This is illustrated in Figure 3-11.

This improved fit takes advantage of the often noted phenomenon that signature clusters tend to be radially distributed (i.e., along straight lines drawn from the origin) and elliptically shaped (i.e., Gaussian statistics). For cases in which this is not a characteristic of the data, an improved fit will not necessarily result from spectral rotation.

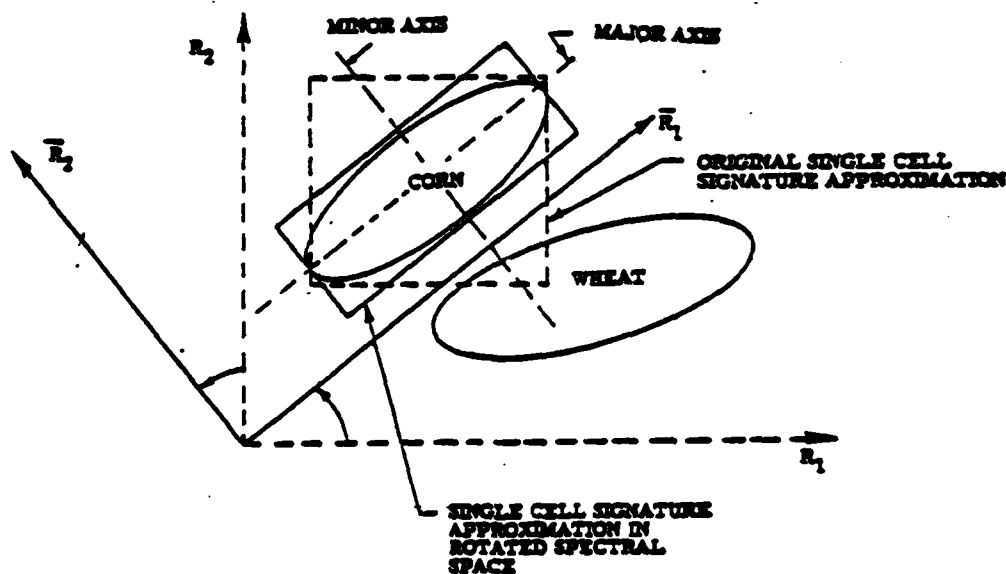


Figure 3-11. Spectral Rotation

* A preprocessing function included here for completeness. See paragraph 3.6.1 for more information.

Interactive Signature Modification

In this mode of operation, the user creates an alarm representing the misclassified area, either by re-executing single cell signature acquisition with a different training site, or by modifying the histogram limits with the original training site. The user, if satisfied that the displayed alarm is adequate, would then subtract the alarm from the results of the initial training operation that contained both correctly and incorrectly classified pixels. The subtraction occurs in the spatial domain but has the effect of modifying the original signature.

The process may be continued (adding errors of omission and subtracting errors of commission) until the user is satisfied with his results.

3.6.2.2 Nonparametric - Multicell Analysis

Multicell Signature Analysis is diagrammed in Figure 3-12. The major steps are discussed below.

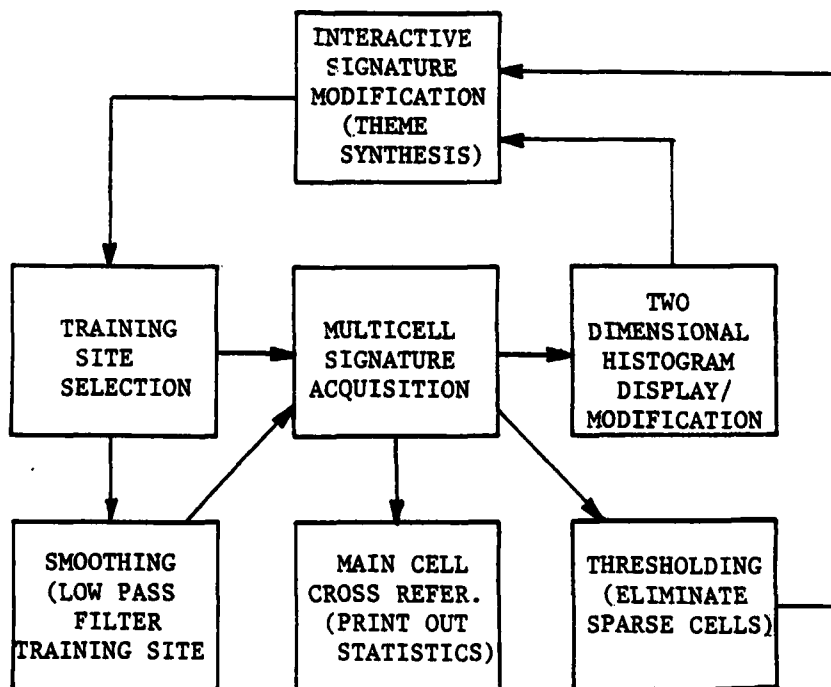


Figure 3-12. Multicell Signature Acquisition

Training Site Selection

As described in paragraph 3.6.2.1, with the additional caution that care must be taken to select a sufficiently large training site, such that the multicell signature will be statistically well represented.

Multicell Signature Acquisition

The single cell approximation is subdivided into many smaller cells. Each of the smaller cells is tested to determine the number of pixels within the training area that have the spectral value (or color) defined by each cell. This defines the multidimensional histogram of the training area. This "N-D" histogram, then, is simply a collection of cells, where each cell occupies a discrete, known region in spectral space and where each cell has some measured frequency of occurrence (i.e., a pixel count) associated with it.

If all "empty" cells are discarded, the retained (nonempty) cells comprise the signature (reference Figure 3-13). The resultant collection of cells is not a perfect fit to the true signature; however, the overlap has been eliminated.

Thresholding

The process of eliminating empty or low count cells is referred to as "Thresholding" and is analogous to the limit modifications discussed previously. Thresholding results in a theme track representing all pixels coinciding with the retained cells. Figure 3-14 illustrates the effect of thresholding on the signature.

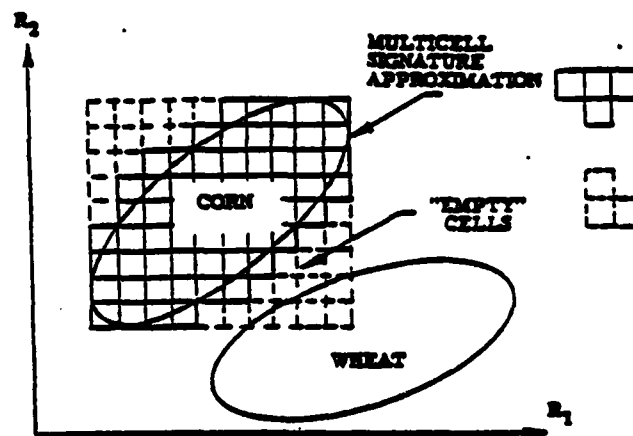


Figure 3-13. Multicell Signature Acquisition

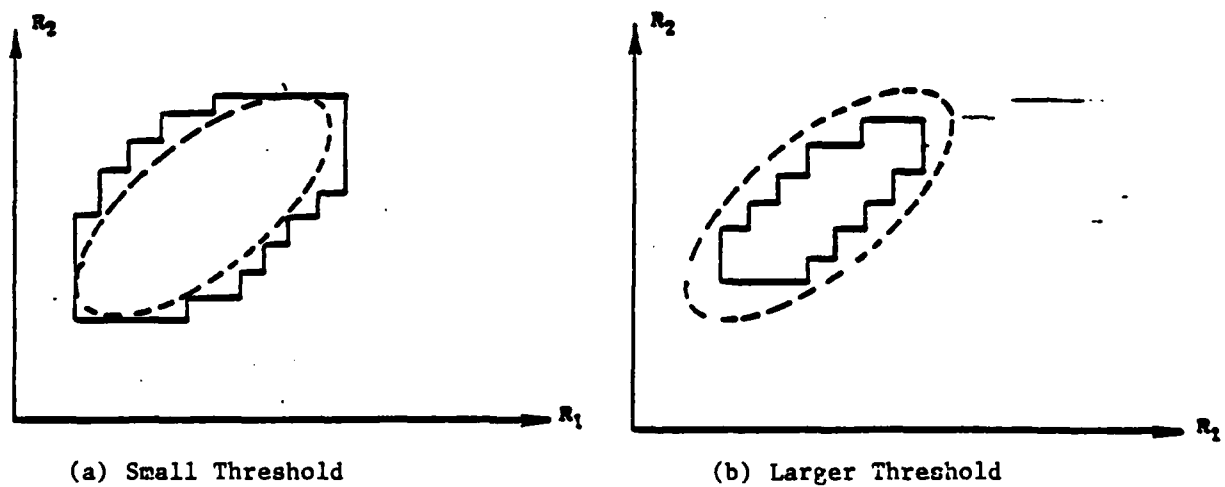


Figure 3-14. Thresholding

Main Cell Cross Reference

The analyst is aided in the selection of proper threshold values by a tabulation of an N dimensional histogram via a Main Cell Cross Reference printout. Cells are listed in descending order based on pixel population.

Two Dimensional Histogram Display/Modification

The analyst is provided a two dimensional projection display of the histogram

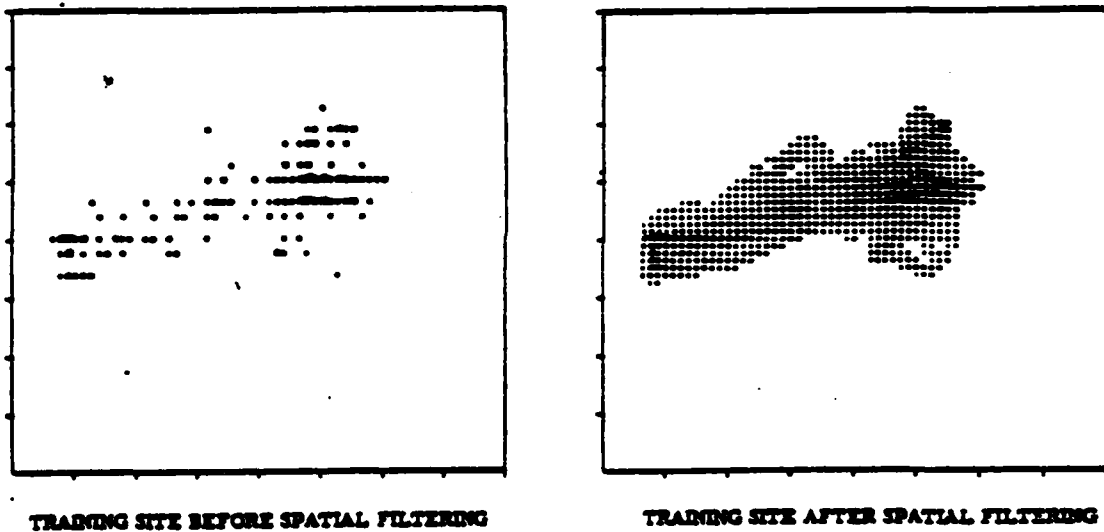


Figure 3-15. Two-Dimensional Histogram Display

acquired earlier. This graphical representation, as shown in Figure 3-15, provides insight into the distribution of the data in feature space. Also, the analyst may select rectangular regions of the scattergram via a terminal cursor, and then alarm the corresponding pixels on the CRT display.

Interactive Signature Modification

This mode operates as described in paragraph 3.6.2.1, except that the alarm/theme results from two dimensional histogram display/modification and/or thresholding. The operator stays in the loop, in both the spatial and spectral domains.

Smoothing (Low Pass Filter)*

The multicell signature may be further processed via a technique known as smoothing. Unless the ratio of pixels within the training site to spectral cells is sufficiently large, the multidimensional histogram will not be statistically meaningful. The histogram is said to be "sparsely populated." Smoothing eliminates the sparseness; in effect, the voids in the histogram are filled. The smoothing actually occurs in the spatial domain; the training samples from which the signature was originally derived are spatially filtered using a $\sin x/x$ interpolator. The multicell signature acquisition process is then repeated for the filtered sampled. Figure 3-15 demonstrates the effect via two scattergrams; one before smoothing and the other after smoothing.

3.6.2.3 Parametric - Gaussian Analysis

Parametric analysis provides the facility to characterize signatures via Gaussian or normal distributions. Gaussian analysis is diagrammed in Figure 3-16; the major steps are discussed below.

* A preprocessing function included here for completeness. See paragraph 3.5 for more information.

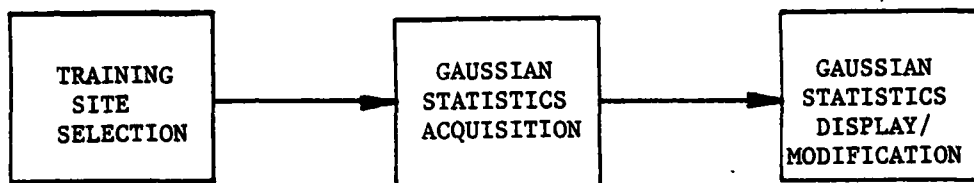


Figure 3-16 . Gaussian Signature Analysis

Training Site Selection

As described in paragraph 3.6.2.1.

Gaussian Statistics Acquisition

The training sample is processed to yield a mean vector, covariance matrix and its inverse, and correlation matrix and its inverse. Graphically speaking, the training sample is fit to an elliptical distribution. The eigenvectors derived from the covariance matrix of the training sample correspond to the direction of the major and minor axes, and the eigenvalues are equal to the length of the

Nonparametric Maximum Likelihood Classifier

This classifier compares the N-D histograms acquired during multicell signature analysis to create a new composite multicell signature, with every cell assigned a unique category. The imagery to be classified is then tested, pixel by pixel, against the signature, resulting in a theme map.

The N-D histogram comparison process resolves conflicts by maximum likelihood probabilities. That is, overlapping cells are assigned to the signature with higher pixel counts (normalized to their respective training sample populations), since cell population is a measure of probability. Figure 3-21 illustrates a three dimensional view of two clusters (probability is the third axis) and the graphical resolution of conflicting cells in favor of the class with higher probability.

Parametric (Gaussian) Maximum Likelihood Classifier

This classifier operates in similar fashion to the nonparametric classifier, except that Gaussian signatures, and therefore normally shaped distributions, are input. The imagery to be classified is then compared to each distribution, pixel by pixel, to determine which is "closest." Closeness to a signature is measured in terms of ellipsoidal units of equidistant contours:

$$\text{Closeness} = \sum_{n=1}^N \frac{(y_n - \mu_n)^2}{n}$$

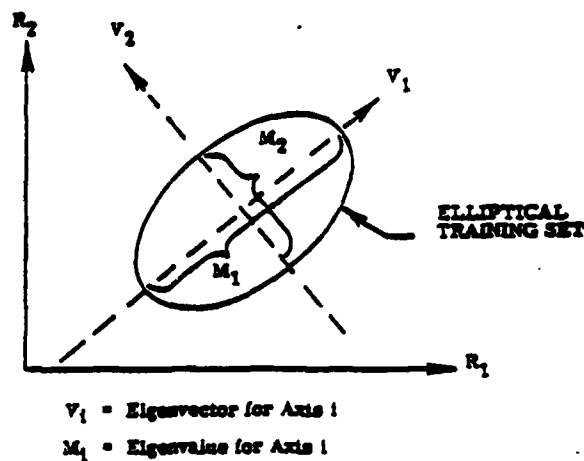


Figure 3-17. Geometrical Interpretation of Eigenvectors

diameters (refer to Figure 3-17).

Gaussian Statistics Display/Modification

The analyst may display the acquired statistics in tabular form, and modify the mean vector and/or covariance matrix terms. Note that an interactive signature modification path is not provided; the presumption is that the analyst has preceded parametric analysis with a period of interactive nonparametric analysis, and thus already has a good feel for the data.

3.6.2.4 Parametric - Cluster Analysis

Cluster analysis is diagrammed in Figure 3-18. The major steps are discussed below.

Training Site Selection

Training site selection for this method differs from all other signature

AD-A091 959

GENERAL ELECTRIC CO LANHAM MD SPACE DIV
ADVANCED SATELLITE HARDWARE/SOFTWARE SYSTEM STUDY.(U)

F/6 22/2

APR 80 R SPENCER, R HO, F KABAT, D M SMITH

DAAK70-79-C-0009

UNCLASSIFIED

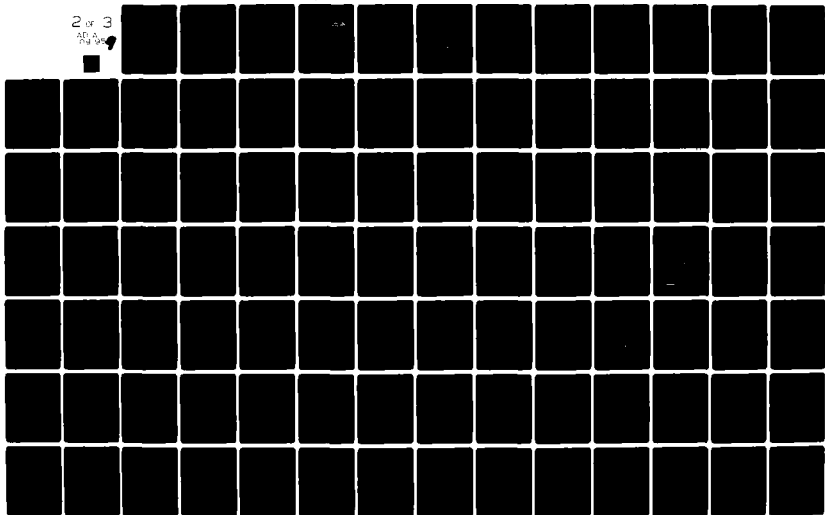
A05D54213

ETL-0225

NL

2 of 3

AD-A091 959



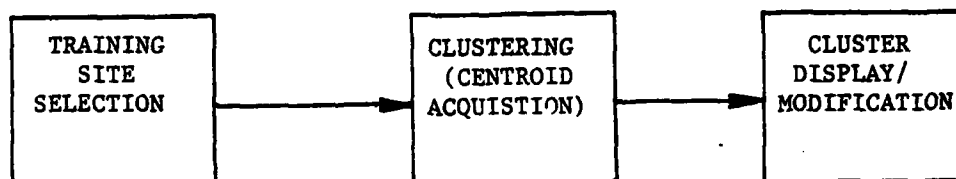
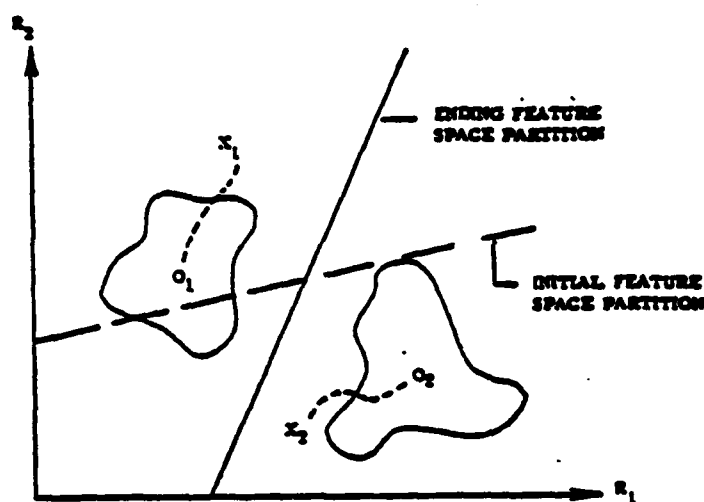


Figure 3-18. Cluster Analysis

analysis techniques, in that a multiplicity of unlabeled categories may exist in the training site (the training site can be the entire screen). For example, the analyst may know that three crop types exist within a given image area, but does not have sufficient a priori knowledge to identify them. Cluster analysis is one method to extract this information.

Clustering

The process of clustering means simply to find natural groupings of data in feature space. A migrating means technique is used to iteratively process all training data through the clustering algorithm until the centroids converge. Figure 3-19 illustrates a two-cluster case.



x_1 = Starting Centroid ("Seed"), Cluster 1

o_1 = Ending Centroid, Cluster 1

Figure 3-19. Cluster Analysis (Two Cluster Case)

Cluster Display/Modification

The analyst may display the cluster centroids in tabular form, and modify them. As in Gaussian analysis, an interactive path is not provided; visual feedback is provided by executing the corresponding classifier.

3.6.3 CLASSIFICATION

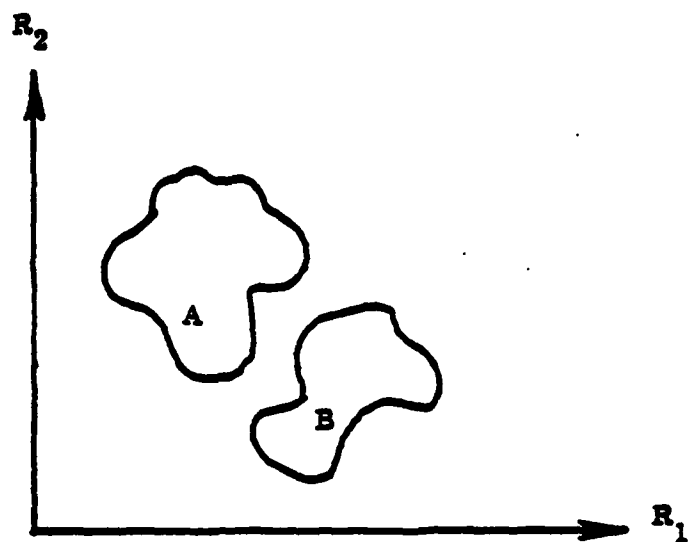
Following signature analysis the analyst would perform classification. The relationship between the analysis technique and classifiers is as follows:

Multicell analysis - nonparametric maximum likelihood classifier

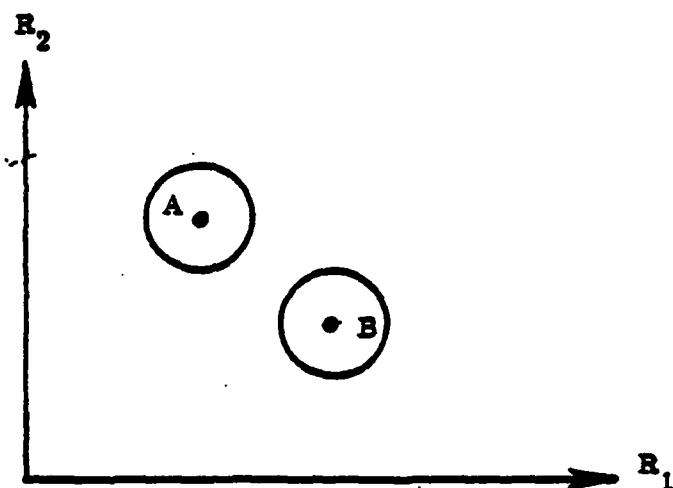
Gaussian analysis - parametric maximum likelihood classifier

Cluster analysis - minimum distance classifier

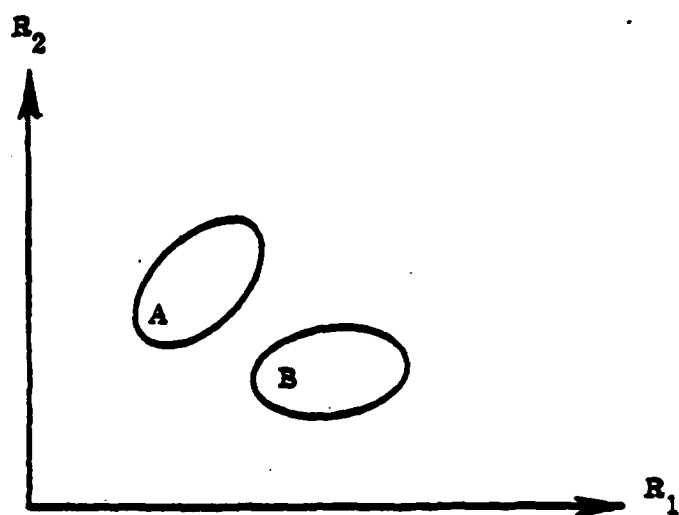
Figure 3-20 illustrates graphically the three classifiers.



NONPARAMETRIC
MAXIMUM
LIKELIHOOD

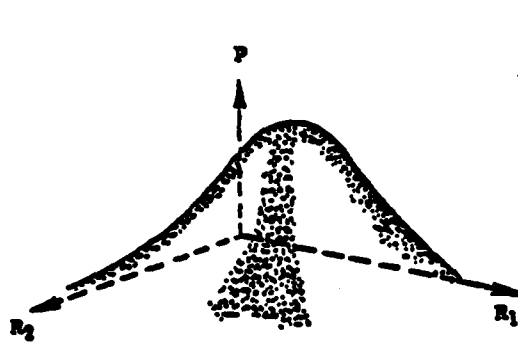


MINIMUM
DISTANCE

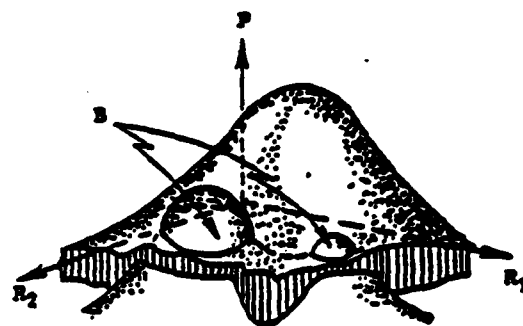


PARAMETRIC
MAXIMUM
LIKELIHOOD

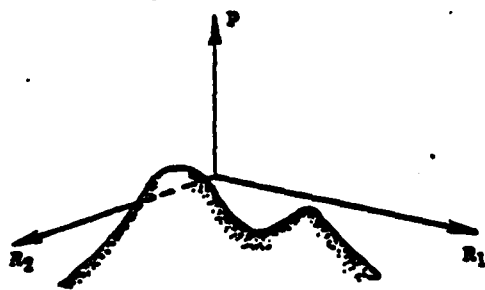
Figure 3-20. Classifiers



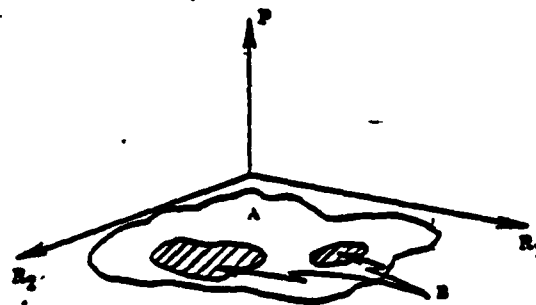
Probability of Membership in Category A



Maximum Likelihood Resolution of A and B



Probability of Membership in Category B



Two-Dimensional Plot of Maximum Likelihood Resolution

Figure 3-21. Nonparametric Maximum Likelihood

Where:

y_n = Coordinate of y in the direction of the n^{th} eigenvector

μ_n = Mean value in same direction

λ_n = Eigenvalue in same direction.

The final step is a comparison of the minimum distance with the user input threshold; if greater, the pixel in question is discarded (i.e., assigned to the "null" class).

If Figure 3-21 utilized normally shaped unimodal distributions, it would be a valid graphical representation of parametric maximum likelihood. A two dimensional illustration is offered in Figure 3-22.

Minimum Distance Classifier

This classifier utilizes the cluster centroids determined during cluster analysis. The imagery to be classified is then compared to each centroid, pixel by pixel, to determine which is closest. Closeness in this case is a simple Euclidean distance (squared) measure; no second order statistics are utilized.

As in the previous classifier, the final step is a comparison of the minimum distance with the user input distance threshold; if greater, the pixel in question is discarded (i.e., assigned to the "null" category). Figure 3-23 illustrates a two-cluster case, with various thresholds.

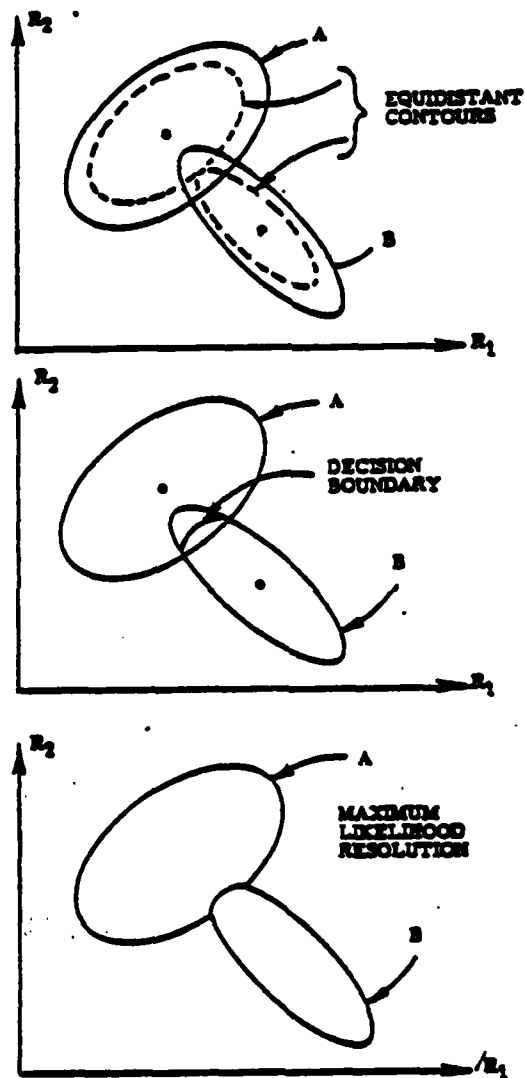
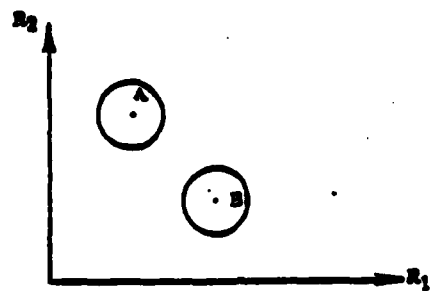
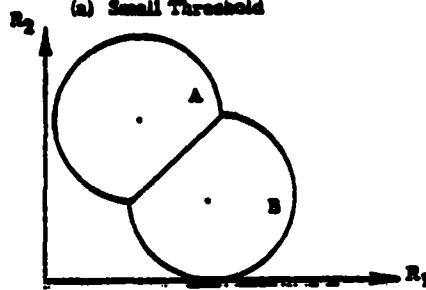


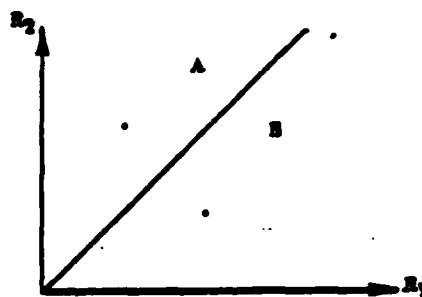
Figure 3-22. Parametric Maximum Likelihood Classification



(a) Small Threshold



(b) Medium Threshold



(c) Large Threshold

Figure 3-23. Minimum Distance Classification

3.7 POST-PROCESSING PROCEDURES

Following the detailed spectral (or spatial/monochrome) analysis, a set of "cleaning up" procedures may be required. These procedures are designed to correct the final product for the effects of noise spikes, missing data or other anomalies in the final product, including the fact that the system operator may have terminated processing at a point at which he is satisfied with the accuracy of a numerical result, but which stops short of generating an aesthetically pleasing product.

Theme Area Fill - A procedure which assumes that any stray pixels in a large homogeneous area are probably misclassified, and arbitrarily defines such pixels to be of the same class as the surrounding area.

Stray Point Rejection - An inverse case of theme area fill, where pixels outside the main theme area(s) are classified to be the same as the main theme. This technique assumes such pixels are misclassified and eliminates them from theme statistics.

Edge Smoothing - The use of spatial filtering to correct for obvious discrepancies in the boundary between theme areas.

3.8 MENSURATION

Following analysis of imagery while using one or several of the techniques described, it is frequently necessary to provide measurements of areas, distances between features and perimeters of discrete areas. Mensuration packages can provide these capabilities.

Theme Area Statistics - This capability is, in essence, a count of the number of pixels to which specific theme characteristics have been assigned. Subsequent scaling to pixel area will then provide theme population statistics for the scene of interest as an area measurement.

Perimeter Measurement - For some purposes it is necessary to determine the perimeters of a theme area, or the length of a boundary between themes. A perimeter measurement package will provide this capability.

Distance and Direction - It may be desirable to determine the distance and direction of features relative to each other, or based on specific geographic location. This can be determined from the pixel count from line numbers corresponding to the feature of interest.

SECTION 4

HARDWARE CAPABILITIES

This section reviews available technology in the major area of Data I/O, Data Storage and Display, and Data Processing, and includes a discussion of human factors considerations in the design of an image analysis system.

The review of available technology includes both off-the-shelf product types as well as those which are known to be under development and may realistically be expected to be available as off-the-shelf products within the 1981-82 time frame (i.e., prior to the anticipated launch of the Landsat-D spacecraft).

4.1 DATA INPUT AND OUTPUT DEVICES

In this discussion of data I/O consideration will be given primarily to the ingest and output of image as graphic overlay data. It is anticipated that normal methods of tabular data input (such as cards, CCT, data entry terminals, etc.) and output (line printers, xerographic or other plotters, etc.) will be available and will normally be incorporated as part of the "standard" computer system used as a host as primary processor for the Image Analysis System.

Image data will be available, in general, as high density tape (HDT), CCT or film products, although alternative methods such as optical disk systems may be used for data dissemination. A similar range of output products will be required, with perhaps greater emphasis on film images and map (graphic) overlays.

4.1.1 MAGNETIC TAPE I/O DEVICES

Magnetic tape I/O devices are, predominately, one of two types - high density digital tapes (HDT) or computer compatible tapes (CCT). Recent additions to the marketplace are the so-called "streaming" tape systems, which are a variant of the CCT. Additionally, the prospect for the use of video cassette recording technology combined with high density analog recording techniques could provide an attractive alternative to HDT type systems.

Typically, the input to the Image Analysis System will be in CCT or HDT format; any magnetic tape output will be CCT only.

4.1.1.1 High Density Digital Tapes

High density digital tape systems will be used extensively in the Landsat-D Ground System, as described in Section 1, for bulk data recording of all data types, from raw data from the spacecraft to corrected data for archival and dissemination purposes. It is anticipated that large volume data users (such as the Corps of Engineers) may be expected to receive much of this routinely requested data as HDT products.

High density digital tape systems use standard 1-inch wide instrumentation tape as the recording medium, and the tape drive mechanism is similar to that used in instrumentation recorders.

The key feature of importance to the users of an HDT product is that the data output is a single serial bitstream. Although data is recorded on tape in a parallel, multi-track format, this is to take advantage of high tape packing

densities (28 tracks, up to 33 kbpI per track) and is transparent to the users. HDT systems are also continuous recording/playback systems. In other words data is read out as a continuous bitstream without blocking and pauses characteristic of CCT systems. A sophisticated electronic interface is thus required to convert data output from an HDT to a form compatible with an image analysis computer system.

In spite of these restrictions and limitations, for bulk data storage and archive purposes an HDT based system is currently the optimum type system, and extraction of scenes from an HDT to CCT products may be performed as an offline function, independent of image analysis activity, or disk files may be loaded direct from the HDT.

As an alternative to the bulk of HDT systems, it is possible for video cassette tapes (using the tape drive and rotating head recording technology of video recorders) to be used to store single TM scenes. It should be emphasized that this is somewhat speculative, and the Landsat program has no plans, at present, to disseminate image data in this form. However, the convenience of the video cassette as a mechanism for storage and dissemination of a single scene makes this an attractive possibility. The serial to parallel interface required by the HDT would still be required for such a system.

4.1.1.2 Computer Compatible Tapes

CCT input and output devices have been standardized and used extensively in the computer industry for many years. Current technology is based on 800, 1600 or 6250 bpi, seven- or nine-track formats. Typically for image data a nine-track

format is used, and this is directly compatible with the eight-bit byte structure of the data. Figure 4-1 shows the comparative capacity of different CCT densities for MSS and TM scenes.

These systems do not offer the high packing density/storage capacity of HDT systems, but do offer the advantage of standardization, low cost, and direct compatibility with computer system I/O parts.

New technology is being developed for CCT products which would quadruple the storage capacity by doubling both data density (to 12500 bpi) and number of tracks (to 18) while retaining the inherent blocked format and capacity for block data transfers to/from the tape medium.

4.1.1.3 Optical Disk Device

Optical disks are a permanent storage media consisting of a plastic plate covered with a thin layer of recording material. Digital data is recorded by using a laser to melt small holes (typically one micron) in the recording material. A laser is also needed to read the permanently recorded data. Although such a system is not currently available, several manufacturers expect to market units by 1981. Preliminary specifications for one system indicate a capacity of 2.5 GB per plate (two sides), an average data transfer rate of about 700 kBps, and an average access time of about 300 milliseconds.

The nature of the interface requirements are not fully known at this time, and it is uncertain as to whether or not the computer interface will be a continuous serial (HDT-like) stream, or blocked parallel (CCT-like) transfers.

NRZI 800 BPI
W/8 KByte Block Size

143 TM reels per
10 scenes

15 MSS reels per
10 scenes

PE 1600 BPI
W/8 KByte Block Size

73 TM reels per
10 scenes

8 MSS reels per
10 scenes

GCR 6250 BPI
W/8 KByte Block Size

21 TM reels per
10 scenes

3 MSS reels per
10 scenes

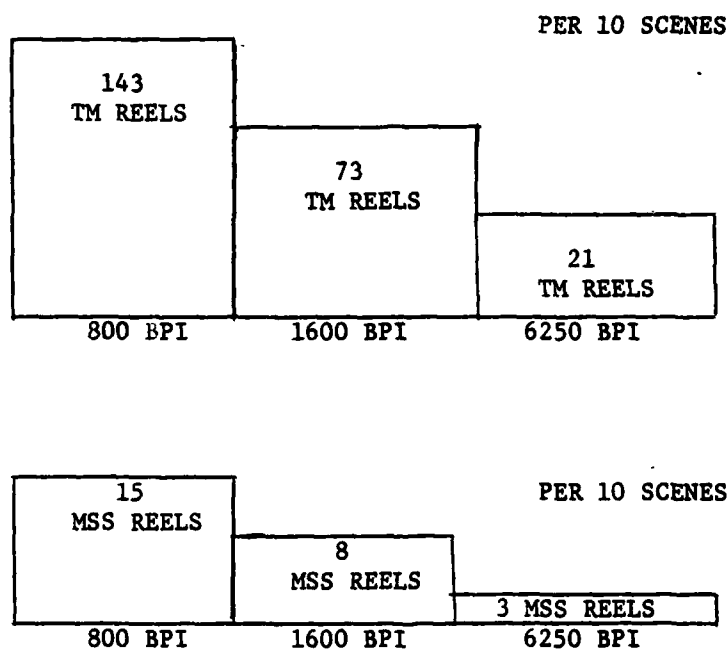


Figure 4-1. Comparative Storage Capacity of Different CCT Formats

4.1.2 PHOTOGRAPHIC FILM I/O DEVICES

Photographic film I/O devices, unlike tape systems, require separate units for data ingest (film scanning) and data output (film recording), although there are combination devices available. The purpose of the film scanner is the generation of digital data for processing by the image analysis system, using black and white or color photographic products as input. The film scanner can also be used to generate, in digital form, images of maps for overlay purposes within the digital system.

The principle of film scanning/digitizers is quite straightforward: a small spot of light is focused on the film to be input to the system and the transmitted amplitude is recorded as a digital value. The spot is scanned, raster fashion, over the image area of interest (which may be the full film image or some subscene). The scanning mechanism may be mechanical (through mirror movement) or electronic (by using a CRT as the light source with a fixed detector, or by using a uniform large area light source with an image dissector tube such as a vidicon or orthicon, as the detector). The different dye layers in color and color IR film are scanned separately using narrow band spectral filters matched to the particular color of interest.

Film recording is the inverse of the scanning process. A spot of light is focused on the unexposed film in the recorder and is modulated in intensity (as if pulsed) the pulse deviation to provide appropriate exposure of the film. Color products may be generated by recording on color film using white light and narrow band filters to expose the different dye layers in the film (color

recording), or by recording separate images on different pieces of film using a monochromatic light source (typically a laser) and combining the images optically during a photographic reproduction process (color separation).

4.2 DATA STORAGE AND DISPLAY

This section presents a discussion of the technology available for data storage and display devices.

Data storage requirements are categorized as two types: short-term storage of an image or subscene, directly accessible by the computer system, and long-term (possibly indefinite) archival storage of bulk data.

Display devices are likewise put in two classes - the primary image display on which a TV-type presentation of the image data is presented, and the interactive graphics terminal device, which is typically a monochrome unit designed simply for the display of alphanumeric and graphic information, and not imagery.

4.2.1 ONLINE DATA STORAGE

Online (or working) data storage for the image analysis system is typically a magnetic disk system. Typical systems may have storage capacities ranging from a few megabytes up to several hundred megabytes if multiple disk spindles are used with a single controller. Data transfer rates are usually compatible with computer bus rates - from 100 kilobytes per second up to approximately one megabyte per second.

The primary considerations for working storage are rapid access and high data transfer rates for a reasonable cost. However, transfer rates should match the

rate at which the receiving device operates; anything faster is excess capability that increases costs. Working storage includes all data storage that must be rapidly available for use by the central processor, by any of the terminals, or by any of the input or output devices. This includes permanent storage of commonly used information, and temporary storage of input data, and intermediate and final results of calculations. For example, in performing a multispectral classification, among the many items that would need to be stored for some period are: the classification algorithm, the TM scene data, the numerical characteristics of the selected training sites, and the final classified image.

Normally tape is not considered suitable for working storage; however in those cases where the data can be put on the tape in the same order that it will later be required, and where a high data transfer rate is not essential, tape may be the best choice. A good example is the temporary storage of processed image data until a film product is generated, since film recorders that will satisfy COE requirements normally do not have very high input data rates, and sequential data transfer is required rather than random access.

A single TM scene (seven bands) contains about 300 MB of data. Often only a part of a scene is of interest for a particular project. Since terminals typically display about 512 x 512 pixels (1.6 MB for all seven bands), this amount of data is often intensively analyzed. Disk storage is well suited to data volumes in this range, at a reasonable cost and with good data transfer rates. Usually scene data is read mostly sequentially so the access time (or search time) of moving head disks does not present any major difficulty.

Storage of applications programs, image processing algorithms, the data base management system, the data base, system programs and the compiler are normally partitioned into semiconductor memory, disk, and tape depending on how often they are used and how much storage volume they require.

For a program to be executed it must first be loaded into the computer main memory, which is usually semiconductor memory but in some cases is still magnetic core memory. This memory can be expanded up to a certain maximum value for each type of computer. Some system software routines are always resident in main memory and other commonly used programs are also resident if room is available. Larger programs are on high speed disk (moving or fixed head). Enough main memory should be available to load the largest programs and execute them, although super large programs can be loaded and executed in parts. In some cases this could require unloading normally resident programs to temporary storage on a disk. To save space and media costs, very large or seldom used programs could be on tape instead of on a disk pack.

The data base normally would be on magnetic disk to allow quick access to all information. Since the data base is usually accessed from a terminal, a response back to the terminal operator in less than several seconds should be satisfactory. This means that high access and transfer rates are not essential; a fairly slow disk should be adequate.

It is very difficult to size working storage requirements because they depend on many variables. The use of removable media is very useful in providing flexibility; if several 14-inch rigid disk units are part of a system this would permit different disk packs to be mounted depending on the circumstances. Disk storage can also be used to store temporary results until needed in later calculations.

The major categories of disk storage systems are floppy disk and various diameter rigid disks.

Floppy disks were introduced a few years ago to provide inexpensive storage for minicomputers. The disks are also removable for use as a long-term storage media. The largest current capacity of one of these units is 6 MB utilizing two eight-inch disks. Typical data transfer rates are 60 kBps with an average data access time of 100-200 milliseconds. Typical units cost \$300-500.

Eight-inch rigid disks are newly marketed devices using new (Winchester) technology to provide low cost storage. The disks are generally not removable. A typical inexpensive unit will store 10 MB, have an average access time of 70 milliseconds, an average data transfer rate of 540 kBps, and cost about \$1,200. The largest capacity system currently available stores 64.5 MB in a multiple disk arrangement, has an average data transfer rate of 1.03 MBps, an average access time of about 50 milliseconds, and costs about \$12,000.

Eleven-inch rigid disks are an outgrowth of the eight-inch rigid disks, providing higher storage capacities. A unit currently advertised to be available

in late 1980 offers 120 MB of storage, an average data transfer rate of 920 KBps, an average access time of 65 milliseconds, and costs about \$4,700. One manufacturer is advertising that by 1981 a capacity of around 300 MB will be available in this format, using both removable and fixed media.

Fourteen-inch rigid disks are the traditional size of rigid disks. Depending on the number of individual platters packaged as a unit (up to ten or more) and the number of spindles used to drive the sets of platters (usually one or two), a wide variety of capabilities is available. Some disk units have many heads (one for each track) to improve data access time (3-10 milliseconds), while others have only one head per platter which moves from track to track, increasing access time but reducing cost and increasing capacity. Many 14-inch systems have performance capabilities similar to the new eight- and 11-inch systems. However, the sets of 14-inch platters (called disk packs) are usually removable for offline storage. The most advanced moving head systems have total data capacities of 1.2 GB using two spindles, each with eight nonremovable platters, an average access time of 22 milliseconds, an average data transfer rate of 1.2 MBps, and cost about \$50,000, which includes some of the controller and interface electronics. Units with nearly one GB capacity per spindle are expected shortly.

A more standard single spindle unit, with 176 MB capacity, an average data transfer rate of 806 kbps, and an average access time of 38.8 milliseconds, costs about \$35,000, including the controller and computer interface. A disk pack for this unit costs about \$750.

4.2.2 ARCHIVAL STORAGE

The primary consideration for archival storage is the ability to conveniently remove the storage medium from the system and keep it for long periods without degradation (in a rack, in another room or building, etc.). Thus, only tapes and removable disks need to be examined for this use. Secondary considerations include keeping the physical volume occupied by the archive to a minimum, ability to access the information in a reasonable time period, and keeping the cost of the storage medium down. For the application being considered here, there are several archives that must be considered, each of which could use a different media depending on specific requirements.

a. Archival TM Scene Storage

A single TM scene (7 bands) contains about 300 MB of data. Since a large number of scenes will be archived, the cost and size of 14-inch removable magnetic disk packs are prohibitive. The only tape formats that can handle more than one scene per reel are HDTs and video cassettes. If the TM data are received on HDTs which already contain only requested scenes, then there is no reason to convert these to another format. If the received data must be edited to remove cloud cover, redundant coverage, extraneous data, etc., then either type of tape could be used for archival storage. The video cassettes are considerably smaller and cheaper than HDTs; however, the HDTs permit faster data transfer rates. One scene can be read from a 28-track HDT in about 100 seconds (at the slowest tape speed, which still means a data transfer rate of 3.2 MBps) while it would take about 25 minutes from a video cassette.

Two other possible media for this type of storage are CCTs and the optical disks expected to be marketed in the near future. If the newest heads are used (12,500 bpi, 18 tracks), a single CCT could hold one TM scene. About three scenes could be put on one optical disk (30 cm. dia.). It would take about five minutes to read a scene from the CCT and about 50 minutes from an optical disk.

b. Ancillary Data Archive

A large amount of ancillary data will have to be stored either near the interactive terminals or near the central data processor. Most of this data will not originally be in computer compatible form, such as maps, water runoff statistics, etc. Items such as maps should be stored in their original form and only converted to a computer compatible format when required.

c. Other Sensor Data

Data from aircraft and spacecraft sensors will often already be in computer compatible forms, usually on CCTs. Data that are used regularly, such as climatic and ground truth information, should probably be routinely converted to a computer compatible form. Depending on the volume of such data, some of it could become part of working storage (described in the next section) or it could all be maintained in offline storage, to be loaded as needed. The preferred storage media for the offline case would be removable disks, which provide rapid access to the many small pieces of information. With the high speed of current computer systems, tape search

times usually are too long to be practical for retrieval of required ancillary data.

4.2.3 REFRESH MEMORY

When TV type tubes are used for display purposes, a complete image must be presented on the screen 30 times each second. To accomplish this the image is stored in what is called "refresh memory" and read out and transferred to the screen 30 times each second. In most configurations the display consists of about 512 image elements across and 512 image elements down or about 262,000 elements, requiring a data rate of 7.9 MBps. If a color display is desired then each of the three color generators require input at 7.9 MBps. For a 1024 x 1024 element display a data rate of over 30 MBps (for each color) is required. Only the fastest solid state devices can supply such high data transfer rates.

For a color display the minimum storage volume needed is about $512 \times 512 \times 3 = 786\text{KB}$. A full TM scene (7 bands) requires about 300 MB; the cost of this much solid state memory would be very high. One advantage that results from using solid state devices is that the fast access times and high data transfer rates allow any part of refresh memory to be displayed within 1/30 second. This permits new images to be displayed essentially instantaneously.

In general, the refresh memory is sized according to the display requirement and the number of spectral channels expected to be operated upon or displayed. Refresh memory is often used as a fast online working storage medium for both the host processor and for special purpose hardware in addition to its function of providing the data source for the image display.

A wide variety of solid state devices based on differing technologies are available, each with advantages for specific applications. Access times as low as 5 ns, with corresponding data transfer rates up to 200 MBps, are provided by some devices. A more typical access time is 200 nanoseconds with an average data transfer rate up to 5 MBps. A 2 kB capacity integrated circuit chip of this type costs about \$10. A faster device, with 30 ns access time and an average data rate of up to 30 MBps, costs about \$60 for a 512 byte capacity chip. Obviously, large volumes of storage of this type can become extremely expensive. In addition, all the associated electronics required to interface these chips to the host system also add significantly to the price. For example, a channel of 512 x 512 pixels x 8 bits/pixel for a commercially available image analysis system currently costs approximately \$6000.

A new development, expected to be available in early 1981, is the concept of "Virtual Refresh Memory" where image blocks are swapped between a large disk storage device and solid state memory. This provides the capability, at low cost, for interactive online access to large image areas, although at a somewhat slower rate than for solid state refresh.

4.2.4 IMAGE DISPLAY

Currently the only viable available image display method that is usable for TM data is a TV type raster scan on a precision CRT (cathode ray tube). As explained in the next section, other display methods cannot quickly handle a solid field image. As part of the CRT display, a refresh memory will be required

to provide a continuous data source explained in the previous section. Most raster scan systems display about 512 x 512 or 1024 x 1024 element images. For displaying TM data each image element would normally be used to represent one pixel, although pixels could be repeated for a "zoom" effect, or averaged together to display large areas. Color will be almost mandatory, to form "false color" images, to display several land use classes at one time, for highlighting certain features, etc. As part of an image display system it will be necessary to have the capability to draw boundaries around areas of interest and to select individual pixels. This requires an external device that controls a cursor or cross-hair that can move across the display screen. Three commonly used operator controlled devices that permit this are a track ball, a joy stick, and a light pen. Most commercially available raster scan systems include at least one of these devices as standard or optional equipment.

4.2.5 INTERACTIVE ALPHANUMERIC/GRAPHICS DISPLAYS

For the user to enter and receive information in a timely manner, some sort of interactive unit is necessary. It is also needed to control the image display device (unless it has its own interactive unit). Interactive units consists of a keyboard for user inputs and a screen that displays the inputs and information from the central processor and the image display device.

There are two types of display devices: raster scan and directed beam. A raster scan or TV type system operates by varying the intensity of a beam that periodically scans across the screen along a fixed number of scan lines from the top to the bottom of the CRT screen, thus filling the whole screen. To prevent

flicker, refresh memory is used to redraw the image 30 times each second. Directed beam systems do not scan in a fixed pattern; rather, the beam moves from point to point on the CRT screen to draw the desired image. Images are composed of straight lines, circles arcs, etc. Currently the maximum number of colors available with directed beam systems is four. Directed beam systems come in two varieties: refresh and storage tube. The refresh variety requires the image to be completely redrawn periodically (usually 30 or 60 times each second) to prevent flicker, and consequently also need a refresh memory in which the image is stored. The storage tube variety utilizes a CRT which does not fade, so that once a figure is drawn it remains displayed until erased. The refresh type can only store and display a limited number of lines, while with storage tubes lines can be added until the screen is filled. The major problems with storage tube systems are that minor changes cannot be made, and once erased the next image must be created from scratch. A memory could be provided to store parts of an image so it could be quickly re-created, but this is not part of commercial systems. The directed beam systems are less expensive for displaying graphs, words, and other line figures because of the large amount of storage needed for a raster scan system. Most commercial interactive displays use the directed beam storage tube system. Raster scan devices provide the most flexibility and if a color system is needed, a large number of colors can be generated (compared to a maximum of four colors for directed beam systems).

The actual choice of the type of interactive terminal display will depend on the specific applications desired. For example, a particularly valuable use of an interactive unit is to show histograms of the data displayed on an image display

device, and then to use a moving indicator on the terminal's screen to select regions of the histogram and request enhancement of the corresponding image pixels. The moving indicator would be difficult to implement on a storage tube system, but would present no problems for a raster scan or directed beam refresh system.

4.3 DATA PROCESSING SYSTEMS

In discussing the data processing element requirements of the image analysis system, it is necessary to distinguish between the processing functions that provide image analysis through mathematical algorithms (the "number crunching" activities) and the processing required for system control, data transfer, and related purposes (the "process control" activities).

Classically, a computer is considered as a self-contained system, consisting of a central processing unit (CPU), a block of memory, and various I/O parts that permit the connection of sundry peripheral devices (disk, tape units, line printers, etc.).

For image analysis purposes, however, it is necessary to separate all functions of the system including those classically considered as computer processing, and allocate them to specific devices. Thus, we consider the CPU as one element of the system, solid state memory another, and so on as shown in Figure 4-2. Thus, although memory is supplied as part of the "computer" it must be sized separately, based on overall system requirements, and computer selection criteria will be a function of memory availability, bus speed, operating efficiency and other factors that will be discussed here.

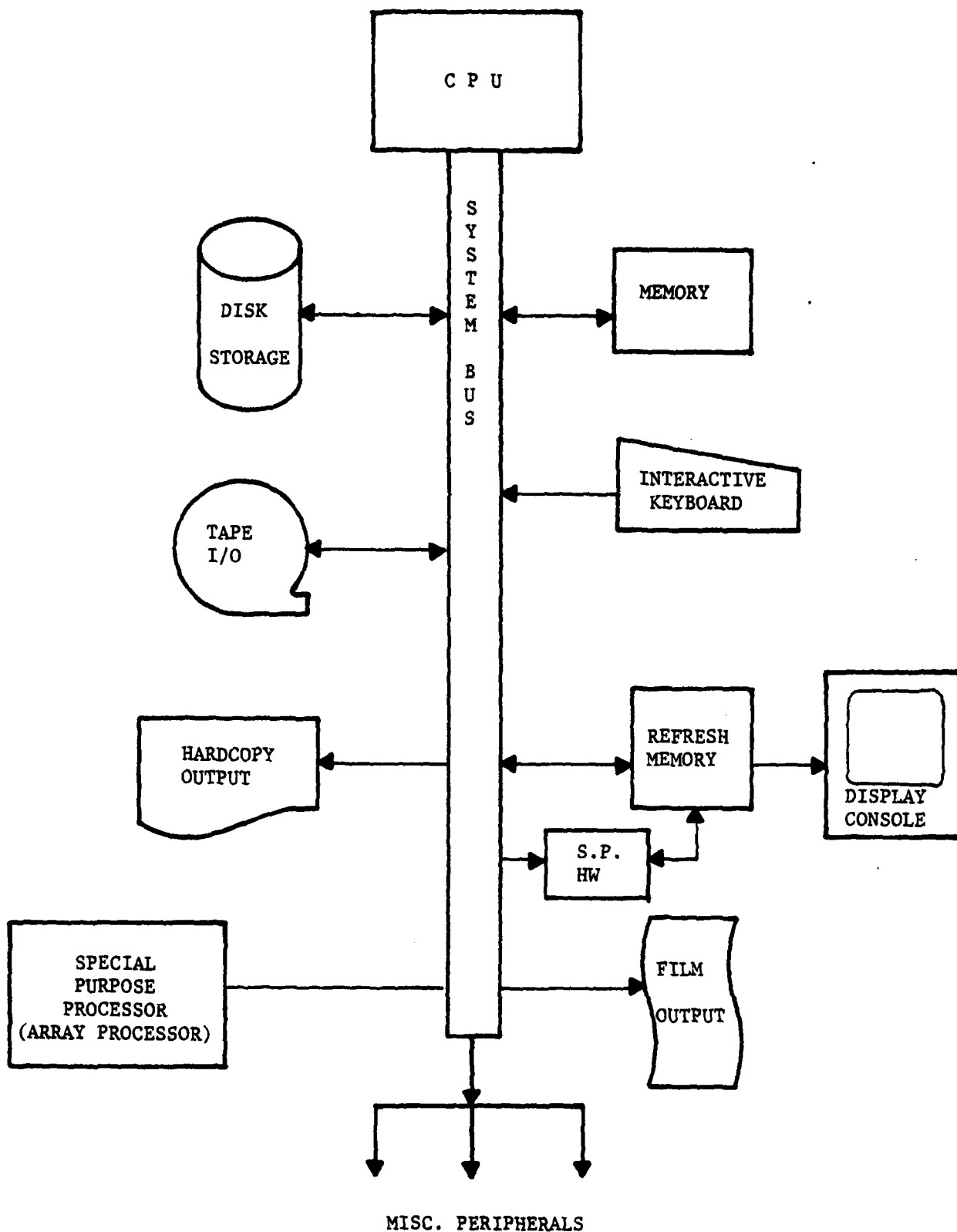


Figure 4-2. Image Analysis System Concept

When considering the overall image analysis system in these terms, it is possible to distinguish between the host processor, special high speed processors for arithmetic operations (such as array processors) and special purpose hardware to perform simple arithmetic and display oriented manipulations.

The use of special purpose hardware and array processors provide a means of overcoming the speed limitation of a host computer. In addition, special purpose hardware may be interposed between refresh memory and the display, thus minimizing refresh memory requirements and reducing data transfers when special display oriented algorithms are invoked. (It is obviously possible to allocate arithmetic functions to the host processor--the degree to which this is done at the expense of other system capabilities, such as throughput, processing response time, etc., is a tradeoff to be performed during a system design phase.)

4.3.1 HOST PROCESSOR

The host processor in an image analysis system is a general purpose computer, sized and selected according to the requirements for both process control and applications analysis functions. With regard to the process control function, however, a distinction must be made between control functions within a console or interactive display terminal, and those required at a system level. Thus, although some terminal designs incorporate microprocessors for internal control, these cannot be considered "host processors" since the terminal itself cannot function as a standalone device.

The process control functions to be performed by the host processors can be characterized as:

- a. Control of ingest of data from external sources (tape, film scanner/digitizer, etc.)
- b. Control of output to external devices (tape, film recorders, hardcopy devices)
- c. Control of data transfers between disk, core memory and display refresh memory
- d. Execution of operations directed by an operator from a keyboard.

These functions may be performed by a dedicated microprocessor or small minicomputer, depending on overall requirement for data transfer speeds, block transfer requirements, etc., with applications analysis performed in a separate general purpose machine. Generally, however, a larger machine is used and the process control functions are combined with some or all of the applications analysis functions provided in the system. As a third alternative, very large applications tasks may be transferred to a central, large mainframe computer for processing on a batch basis while the image analysis system is used for other tasks.

In making a selection of a machine for use as the host processor, a careful analysis of its functions must be performed, in the content of the overall system requirements, and then matched to the functional characteristics of the processor. Table 4-1 shows the factors to be considered and the relationship between the image analysis system requirements and the host processor attributes.

Table 4-1. Relationship Between CPU Functional Capabilities and Image Analysis System Functional Requirements

CPU FUNCTIONAL CHARACTERISTICS	APPLICATION TO IMAGE ANALYSIS SYSTEM	IMPACT ON DESIGN METHODOLOGY, TRADEOFFS REQUIRED, ETC
MEMORY	<p>Required for:</p> <ul style="list-style-type: none"> • Program storage • Data storage and buffering during peripheral devices • Data storage during applications analysis operations 	<p>An analysis of minimum memory requirements for operating system, I/O buffers and applications software must be made. If the physical address space of a candidate machine cannot satisfy the requirement then consideration must be given to more complex software methods, such as the use of overlay structures where software packages are retrieved from disk storage as needed. The tradeoff to be made is one of software complexity and processing speed penalty versus hardware cost and availability.</p>
CACHE MEMORY	<p>Provides a means for more rapid retrieval of data from main memory by adding a small amount of memory directly associated with CPU, and retrieving data from main memory in larger blocks each time an access is made.</p>	<p>Cache memory is provided in more sophisticated minicomputers. Its operation is transparent to the system user, so the system design criteria is one of cost vs processing speed for large programs.</p>
PERIPHERAL DEVICE SUPPORT	<p>An image analysis system will require several standard peripherals together with non standard devices such as film digitizers and recorders, display devices, etc.</p>	<p>The CPU must be compatible with the desired complement of peripherals in terms of physical I/O post availability as well as I/O speed. It is highly desirable to implement a system using standard peripherals, supported by the CPU manufacturer where possible so that all software required for peripherals is available as standard packages.</p>
DIRECT MEMORY ACCESS	<p>Provides an essential ability to input data directly from a peripheral to memory (or from memory to a peripheral) without the need for CPU involvement. Thus, data transfers can take place without disturbing a process continuing in the CPU.</p>	<p>Lack of DMA capability will result in slower I/O rates and in a reduction in overall system processing throughput.</p>

Table 4-1. Relationship Between CPU Functional Capabilities and Image Analysis System Functional Requirements (Continued)

CPU FUNCTIONAL CHARACTERISTICS	APPLICATION TO IMAGE ANALYSIS SYSTEM	IMPACT ON DESIGN METHODOLOGY, TRADEOFFS REQUIRED, ETC.
INPUT/OUTPUT BUS BANDWIDTH	<p>The I/O Bus is the "main highway" connecting all peripherals and the CPU and memory. Since (assuming the use of DMA channels) data transfers between peripherals require two passes along the bus (peripheral A to memory, then memory to peripheral B) and large quantities of data must be transferred, e.g., image data from tape to disk, etc., a high bus bandwidth is indicated.</p>	<p>Some processors use a bus structure which permits the use of several buses simultaneously, or with a very high I/O bus bandwidth. The bus bandwidth directly affects system throughput, and must be matched to the full complement of peripherals. Note that the bus bandwidth and the peripheral data transfer rate are only loosely related--clearly the bus bandwidth must be higher than the data transfer rate, but buffering at the peripheral interface can be used to advantage to make effective use of a much higher rate. Also, if bandwidth is sufficient, several I/O processes may be performed simultaneously.</p>
MEMORY SPEED	<p>Relates directly to system throughput.</p>	<p>The use of cache memory can increase the effective speed of memory access in the event a slower memory type is used. Generally, the highest available speed should be selected.</p>
INSTRUCTION EXECUTION TIME	<p>Provides a measure of the speed with which image analysis tasks are performed.</p>	<p>Generally the highest available speed (lowest execution time) will be selected, consistent with cost considerations.</p>
HARDWARE MULTIPLY/DIVIDE, FLOATING POINT ACCELERATOR	<p>Special purpose circuitry within the CPU provides a significant reduction in the execution time of multiply/divide and floating point arithmetic operations.</p>	<p>The incorporation of hardware for these functions is a low cost method of improving overall system throughput.</p>
WORD LENGTH	<p>The word length used by the CPU has direct bearing on speed and efficiency of operation. In general, the longer the word length, the greater the speed and efficiency of the machine.</p>	<p>Use of a longer word length is highly desirable. In addition, since Landsat image data is standardized on an 8-bit byte format, it is desirable that the word length be a multiple of 8 bits. Thus, 16 or 32 bits are preferred. A 24 bit machine would also be acceptable, though rather more unwieldy, and the loss of efficiency in storage and data transfers would prejudice against use of an 18 or 36 bit machine.</p>

Table 4-1. Relationship Between CPU Functional Capabilities and Image Analysis System Functional Requirements (Continued)

CPU FUNCTIONAL CHARACTERISTICS	APPLICATION TO IMAGE ANALYSIS SYSTEM	IMPACT ON DESIGN METHODOLOGY, TRADEOFFS REQUIRED, ETC.
EXTERNAL INTERRUPTS	<p>The nature of image analysis processing with its requirement for large volumes of data transfer and the requirement for operator interaction with the system dictates that the CPU must have a good external interrupt structure with several priority levels.</p>	<p>Lack of an adequate interrupt priority structure will mean that each time an interrupt is received the CPU must halt all processes to service the interrupt. An adequate priority structure will halt the processor only for urgent tasks, such as initiating a DMA transfer, and allow processing to continue to a convenient break point for lower levels of priority.</p>
SOFTWARE AVAILABILITY	<p>A full software capability is required, with one or more high level languages (FORTRAN, PASCAL, etc.) available for generation of applications software. System software should include device drivers for the peripheral devices as far as possible.</p> <p>A language and/or operating system implemented in firmware frees up more memory space for the user's programs and data. Also, the microcode is usually inaccessible to the user (generally contained in read-only memory), eliminating any possible tampering with the language processor or operating system and reducing chances for error. A third advantage derived from firmware implementation is the ability to create more sophisticated and complex system functions at the hardware level. Microcode routines can be substituted for often-used sub-routines, thereby increasing system performance.</p>	<p>A discussion of software requirements is presented in section 6.</p>

4.3.2 SPECIAL PURPOSE HARDWARE

In order to speed up certain aspects of display or applications processing, special purpose hardware may be used. (The hardware floating point accelerator incorporated in many minicomputers is one form of special purpose hardware, although usually considered part of the CPU.)

Generally, special purpose hardware devices are interposed between the refresh memory and the display device, and may perform their function repetitively, each refresh cycle, or the output from the process, may be returned to a separate block of refresh memory, depending on the availability of refresh memory and the tradeoff of processing speed (and cost) versus memory cost.

Typically, special purpose hardware consists of a set of lookup tables that can be programmed to provide a transfer function (linear, nonlinear or segmented) or in some cases a thresholding function. More complex algorithms can be implemented using table lookup combined with logic elements, or by using register arithmetic to provide high speed addition, subtraction, multiplication or division. One form of hardware used for more complex functions is the pipeline processor, where a number of stages are combined in sequence, and each stage performs the same operation on successive data elements or groups of elements.

Special purpose hardware may be preprogrammed, controlled by operator input, or, more usually, controlled by the host processor. In this case the host processor

will compute the desired transfer function of output pixel value as a function of input value, and will load the lookup table. Incoming data will then be used to address the table, and the contents of that storage location used as the output. This technique is eminently suited to image data analysis, since the work length is generally eight bits, and the lookup table then requires a total of 256 entries.

A more complex example of the use of special purpose hardware is the combination of a set of lookup tables with a set of logic elements to perform a classification task. If we assume that a particular class is represented by pixel values

X_1 to Y_1 in spectral band 1

X_2 to Y_2 in spectral band 2

X_n to Y_n in spectral band n

transfer functions can be set up in table 1 to n so that the output is .TRUE for the desired range, and .FALSE. for all other input values. If these outputs are then combined logically through an n-input AND circuit the final output will be .TRUE. if the pixel belongs to the class, and .FALSE. if it does not. Then outputs can then be stored as a single bit representation in another section of refresh memory, for readout as an overlay if desired.

4.3.3 ARRAY PROCESSORS

An array processor is a particular case of special purpose hardware in that it is a programmable device. An array processor (AP) is a peripheral device, requiring connection to the control and data lines of the host processor in an

image analysis system. The host processor sends instructions to the AP, which then retrieves the required data from the appropriate storage location and performs the desired calculations.

Array-processor calculations are as much as 10 to 1,000 times faster than those of processors. APs use high-speed logic circuits extensively and use 32 or 64-bit numbers in calculations to give greater accuracy than that attained with standard 16-bit minicomputers, and also contain special calculating circuits to process floating point numbers.

Conventional computers operate from a single computer program and carry out one operation at a time. Array processors, on the other hand, can perform several operations simultaneously. AP circuits that carry out such task as calculations and input/output operations are separate processors, each following its own program. Thus, an AP doing calculations need not stop while the input/output processor accepts or outputs data. In contrast, a computer's calculating circuits generally halt while the machine performs an input or output task.

The next effect of using the array processor as a peripheral device in a computer system is to provide an expansion of system capabilities by increasing the number of arithmetic operations and at the same time significantly reducing memory activity in the host computer. This allows the host computer to respond more efficiently to the realtime operating system environment and also increases the processing throughput rate by one to two orders of magnitude. Since most of the array processing software resides within the peripheral, it is only the driver software and the interface hardware that must be made specific for the

host computer. Everything else is independent of the particular computer system upon which it is installed. More significantly, the software responds to Fortran subroutine calls and the user often cannot distinguish between operations performed within the host and those performed in the array processor. This feature alone results in substantial economic benefit by retaining the bulk of the operational user software.

4.4 HUMAN FACTORS ELEMENTS

When generating a system design for an image analysis system, it is necessary to relate the system capabilities to consideration of human factors elements, so that the system is as easy to use as possible, thereby reducing operator fatigue and the possibility of operator error.

Human factor considerations can be categorized into three broad groupings:

- a. Operator input devices
- b. Display characteristics
- c. System responses to operator inputs.

Considerations to be applied to each of these categories are discussed briefly below.

4.4.1 OPERATOR INPUT DEVICES

Operator input devices used in image analysis systems are:

- a. Alphanumeric keyboard
- b. Special function keyboard
- c. Selector switches

- d. Momentary switches
- e. Light pen
- f. Trackball
- g. Joystick.

Each type of device will be defined and its salient characteristics described. An alphanumeric keyboard is essentially a typewriter keyboard, with some additional control keys to perform text control functions. Since all communications with the system are performed using upper case characters, only certain combinations of SHIFT plus other alphanumeric keys or CONTROL plus other alphanumeric keys may be assigned as system control or text editing functions, such as EXECUTE, EXIT, DELETE, INSERT, etc. The alphanumeric keyboard is used as the primary "conversational" input device to the system.

Special function keys are keys that invoke a specific software package at the press of a single key. The initiation of much software action may require additional inputs from an alphanumeric keyboard.

Selector switches are used to define hardware configurations or hardware assignments. In some cases a "Digidial" switch or a rotary switch may be used to input fixed identifiers into the system.

Momentary switches provide a simple means of controlling, via hardware, a discrete stepping function, for example moving a cursor by a fixed amount (usually one pixel) in a direction dictated by a switch closure.

A light pen is used to interact directly with a display to provide some form of electronic masking in the system. For example, using an alphanumeric display to provide a "menu" of alternate actions, the desired alternative may be selected by pointing at an identifier with the light pen. Another application of a light pen is in the identification of a polygonal region on the image display, where the light pen is "pointed" at each vertex of the desired polygon.

A trackball may be a one- or two-dimensional device. It provides a potentiometric (analog) input to the system that may be used to move a cursor, control the size of an enclosed area by shrinking/zooming along orthogonal axes, or scroll an entire image in X or Y. In its one-dimensional form, a trackball provides adjustments in X and Y independently, in its two dimensional form it creates simultaneous variable X and Y outputs, and thus allows for control in diagonal directions.

A joystick is another form of two-dimensional analog input device, and may respond either to position of the stick or to force applied to the stick. The basic difference between the trackball and the joystick in application is that the amplitude of the control signal is directly tied to position in the case of a trackball; however, for a joystick the rate of change of control signal amplitude is proportional to displacement from a zero position, or to force applied. Thus, for example, cursor position will be directly tied to trackball position, whereas cursor movement is controlled by a joystick.

4.4.2 DISPLAY CHARACTERISTICS

System requirements for display devices can be categorized as image, graphics, or alphanumeric types.

Image displays are those in which color or monochrome images are displayed with intensity variations representing the actual intensity of each pixel, and with a high degree of geometric fidelity.

Graphics displays are those in which color or monochrome images are used to display line or bar graphics, or multi-color overlays without intensity variation.

Alphanumeric displays provide the capability for display of textual or numerical information.

In general, graphics display devices (whether monochrome or multi color) will have an alphanumeric capability; the reverse is not true however.

In an image analysis system the primary display is an image display. Text and graphics may be overlaid on this display to provide enhancements, annotation of the image or features within the image, or for graphical representation of image characteristics, such as a histogram or a one-dimensional plot of amplitude vs. linear position. The use of such a combined system has some advantages, however, it is generally more useful to provide a separate alphanumeric/graphic display that provides the complete capability for both interaction with the system (display of menus, processing options, etc.) and for graphical representation of data characteristics, such as one- and two-dimensional histograms, nonlinear transfer functions, and other information related to but not registered with the image data.

SECTION 5

SOFTWARE

This section describes typical software requirements for an Image Analysis System. The structure described is based on that of a currently available system; however, it is representative of the structure and typical modules that would be required for any system. It should be recognized that, because of the use of an existing system as the basis for this description, some functions are described as being performed by an array processor, others by the host CPU. In practice, a specific system functional allocation would be made in developing a new design, and the mix of array processor and CPU functions, and indeed functions performed in special purpose hardware, would differ somewhat from that shown here.

5.1 SYSTEM SOFTWARE

The system software consists of the following major components that provide the operating environment for both hardware functions and applications software:

- a. Session (interactive) executive
- b. Batch executive
- c. Subroutine libraries
- d. Pre-operations
- e. Monitor Console Routines (MCR)
- f. Standard host processor utilities
- g. Array processor utilities
- h. Non-standard device handlers
- i. Spoolers

Following a brief introduction to the key terminology, the system software components are discussed. Emphasis is on operational aspects of the system software.

5.1.1 INTRODUCTION

The following key concepts or features are discussed briefly:

- a. Activity
- b. Session
- c. Environment (batch/interactive/null)
- d. Job.

An activity is a task or collection of tasks that performs a specific image processing function (such as signature acquisition, etc.). Typically each activity corresponds to a single menu selection (in the interactive case) and vice versa. A multitask activity always has a single controlling task. The task name and activity name are identical. Activities are sensitive to the environment (batch vs. interactive).

A session is a period of interactive image processing to process/display image data stored on disk, tape, or the Image Analysis Console (IAC). The session exec task is the primary interface between the analyst and the computer. Tasks (and therefore activities) execute in one of three environments: batch, if executed during a job; interactive, if executed during an interactive session; otherwise, a null environment. A null environment is the standard environment.

A job is the sequence of one or more tasks invoked between a JOB card and an EOJ card. The JOB card sets up a batch environment for these tasks, and EOJ restores the null environment. Activities executing in batch mode retrieve their parameters from disk files. Batch is typically used for:

- a. Long, nonvisible image processing
- b. Development and testing
- c. Card entry.

5.1.2 SESSION (INTERACTIVE) EXECUTIVE

A session is a period of interactive image processing, typically using an alphanumeric/graphics terminal, AP and Image Analysis Console (IAC) to process and display video data stored on disk, tape, or the IAC. A successful interactive system requires rapid response and a simple man-machine interface. Thus, interactive users are given priority for allocation of image processing resources. Also, the design of the man-machine interface shields the analyst from all but image processing related details, yet allows a sophisticated user to easily invoke all available system features during an interactive session.

5.1.3 SUBROUTINE LIBRARIES

These standard subroutines support interactive and batch activities as well as system software programs.

5.1.4 PRE-OPERATIONS

This is a high level system exerciser to verify system operability on a daily basis. The host processor and peripherals, an array processor, and the console are exercised.

5.1.5 STANDARD UTILITIES

These CPU vendor-supplied tasks are used primarily to support program development. Typically these include:

- a. Fortran compiler
- b. Assembler
- c. Task builder
- d. Line text editor
- e. Peripheral interchange program.

5.1.6 ARRAY PROCESSOR UTILITIES

An array processor must be well supported to aid program development. The AP utilities will be compiled on the host processor and include:

- a. Cross-assembler
- b. Linker
- c. Debugger
- d. Simulator.

The simulator is a convenient tool in bringing up new AP programs offline without interfering with operations.

A comprehensive math library is usually included with the AP; this contains subroutines written in AP assembly language that are callable from host computer programs using the AP handler.

5.1.7 NON-STANDARD DEVICE HANDLERS

These are non-standard only in the sense that they are not normally supplied by

the host processor vendor; however, peripheral device handlers, or device drivers, must all interface with the host operating system using vendor conventions.

5.1.8 SPOOLERS

Spoolers are required to support all activities requiring double-buffered data transfers between devices; for example, disk to AP to refresh, or IAC to AP to IAC.

5.2 APPLICATION SOFTWARE

Application software consists of the interactive and batch activities (tasks) that perform the various image processing functions. Figure 5-1 shows the structure of the application software. To assist in determining the mode and resources used, the "I" (interactive), "B" (batch), and "A" (AP) utilization codes accompany each function.

5.2.1 DATA LOADING

Data loading involves the transfer of imagery from tape to disk. The input imagery is full frame Landsat data, and is stored on disk in a band sequential (3SQ) format. Limited radiometric and geometric preprocessing functions are supported; skew correction, scaling, spatial formatting (mapping), and mirror image correction.

Batch processing tasks utilize the AP to perform the selected preprocessing functions. That is, the data flow is from tape to core to AP to disk.

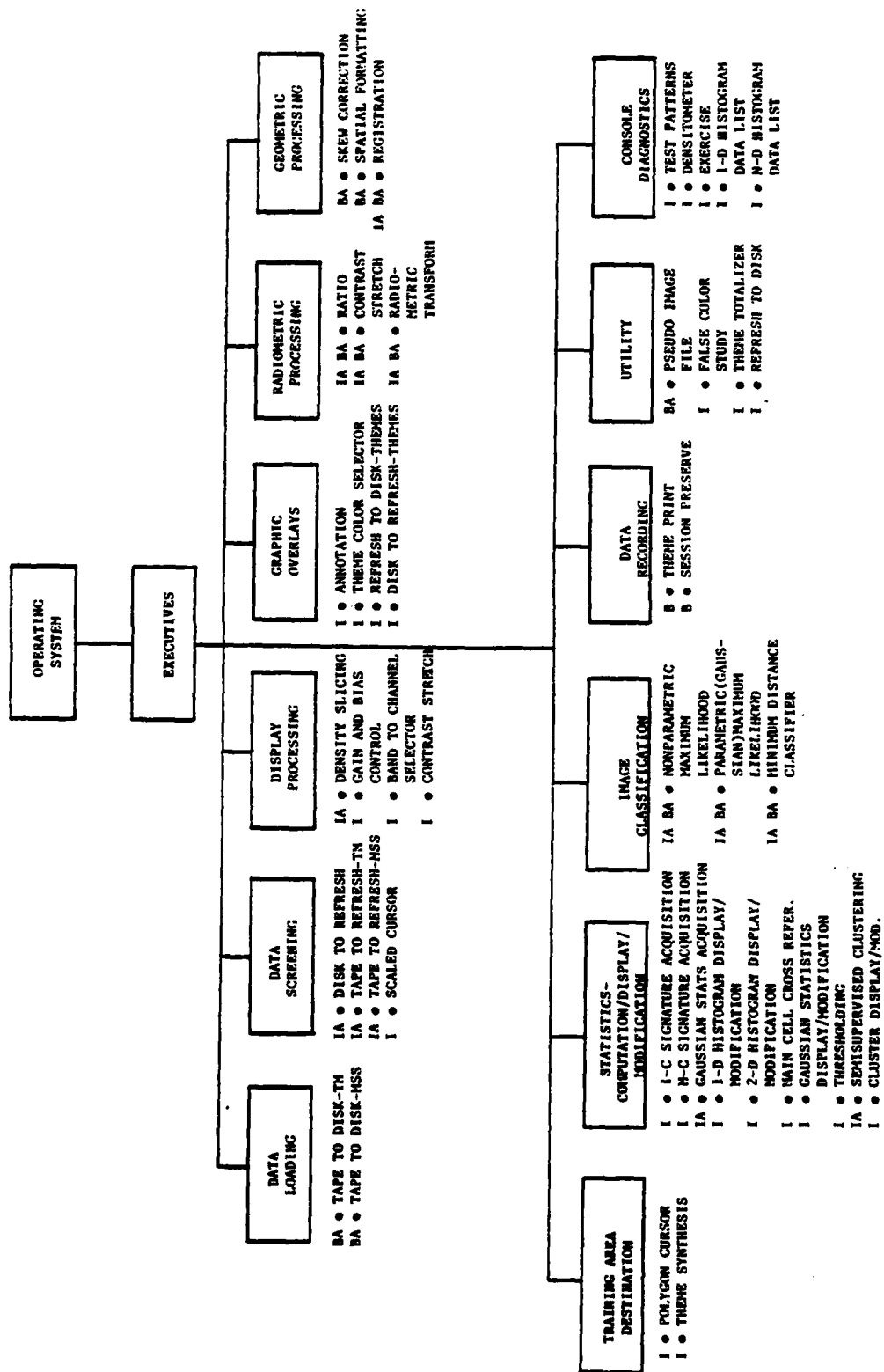


Figure 5-1. Application Software Overview

The preprocessing functions required are:

- a. Amplitude Scaling - Integer multipliers shall be allowed for each channel.
- b. Skew Correction - As described by paragraph 5.2.6.1.1.
- c. Mirror Image Correction - Each scan line is reversed, right to left. Optionally, the image may be reversed top to bottom.
- d. Mapping - As described by paragraph 5.2.6.1.2 except 1:1 nearest neighbor resampling only.

5.2.2 DATA SCREENING

Data screening tasks read data from disk or tape, perform limited preprocessing, and output the data to the refresh memory, either in "paint" or "scroll" mode. A support task is also included, called scaled cursor, to assist the analyst in the selection of mapping coordinates. All of the tasks are interactive tasks.

The user interaction prior to initiation of the actual data screening process requires the analyst to input identification parameters.

Once the screening process begins, the analyst has the option of stopping the process at any time. He may then modify any or all of the input parameters, and continue.

The processing functions include:

- a. Amplitude Scaling - Integer multipliers shall be allowed for each channel.
- b. Skew Correction - As described by paragraph 5.2.6.1.1.

- c. Mirror Image Correction - As described by paragraph 5.2.1.
- d. Mapping - As described in paragraph 5.2.6.1.2.
- e. Scroll/Paint - The display shall be operable in either scroll or paint (static) mode. Scroll is supported in both vertical directions. Scroll speed is selectable. The scroll is stoppable, and the current line then returned to the analyst.
- f. Channel Assignments - The selected disk/tape channels are assignable to any of the available refresh memory channels.

The frame to scene mapping procedure is illustrated in Figure 5-2. Landsat MSS A, B frame coordinates are used for illustrative purposes only; the frame size is dependent on the image type. The following three examples illustrate the types of mapping that are commonly employed:

- a. Overview (sampled) - The full frame of data is sampled such that an overview of the entire frame is displayed. For Landsat, this means that every Nth pixel in x and every Mth pixel in y is retrieved and stored in the refresh memory.
- b. Full Resolution/Split Screen - Every pixel in a selected 256 by 256 portion of the frame is mapped to the first quadrant of the refresh memory.
- c. Full Resolution/Moving Window - The above examples operate in "paint" mode. This example utilizes the moving window feature such that each line of data (512 pixels long) is written to the bottom line of the display and a scroll up command issued. A reverse mode is also available, in which data is written to the top line of the display and a scroll down command issued.

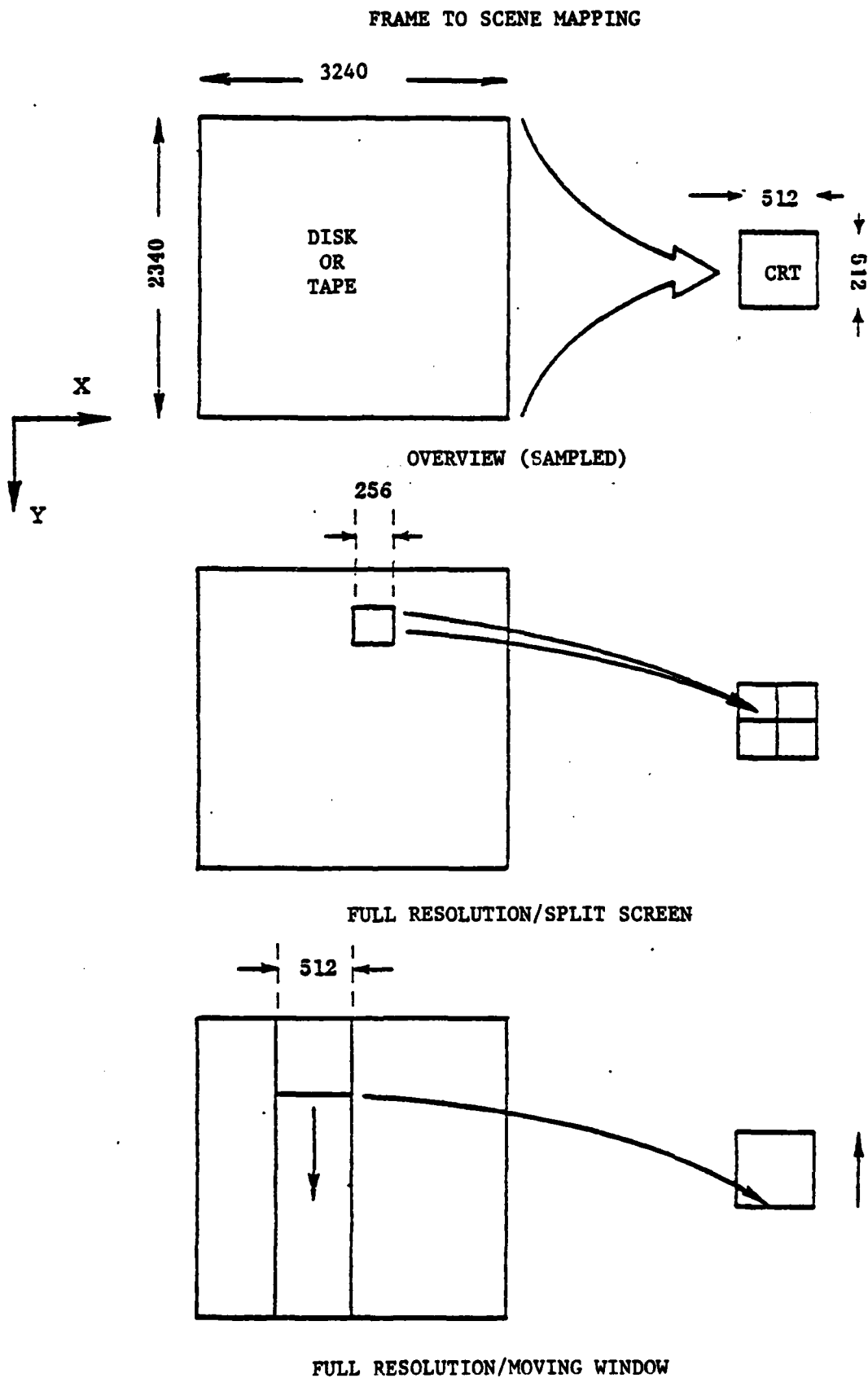


Figure 5-2. Frame to Scene Mapping

These tasks utilize the AP to perform the required radiometric and geometric processing.

5.2.2.1 Scaled Cursor

Scaled cursor is used to assist the analyst in the identification and retrieval of test scenes from full frame data bases.

5.2.3 DISPLAY PROCESSING

The tasks described below perform nondestructive radiometric processing on the image data. That is, the imagery stored in the refresh memory is manipulated in near real-time for display purposes but without affecting the refresh memory contents. All tasks are interactive.

5.2.3.1 Density Slicing

This task slices the minimum-to-maximum brightness range of any single video channel into one-to-sixteen slices. The pixels whose amplitudes fall within a given slice are assigned a unique code for that slice and subsequently displayed in the color assigned to that code.

5.2.3.2 Gain and Bias Control

Near real-time digital gain and bias adjustment is provided for each of the available refresh channels independently by this task. Two modes are provided; manual and interactive. In both modes the function memories in the console are utilized to perform the radiometric computations at display rates.

a. Manual mode

The analyst uses the keyboard to enter gain and/or bias values. A translator program converts gain and bias to function memory table values, then the memories are loaded.

b. Interactive mode

The joystick is utilized to increase or decrease the gain and bias values for the selected monitor channel.

Once initiated, the task simply monitors the cursor counters; whenever a change is detected due to joystick movement, the bias and/or gain values are updated, translated, and sent to the function memories. The tables are transmitted during vertical retrace to avoid picture breakup.

Figure 5-3 illustrates the computation of the transfer function as a function of bias and gain.

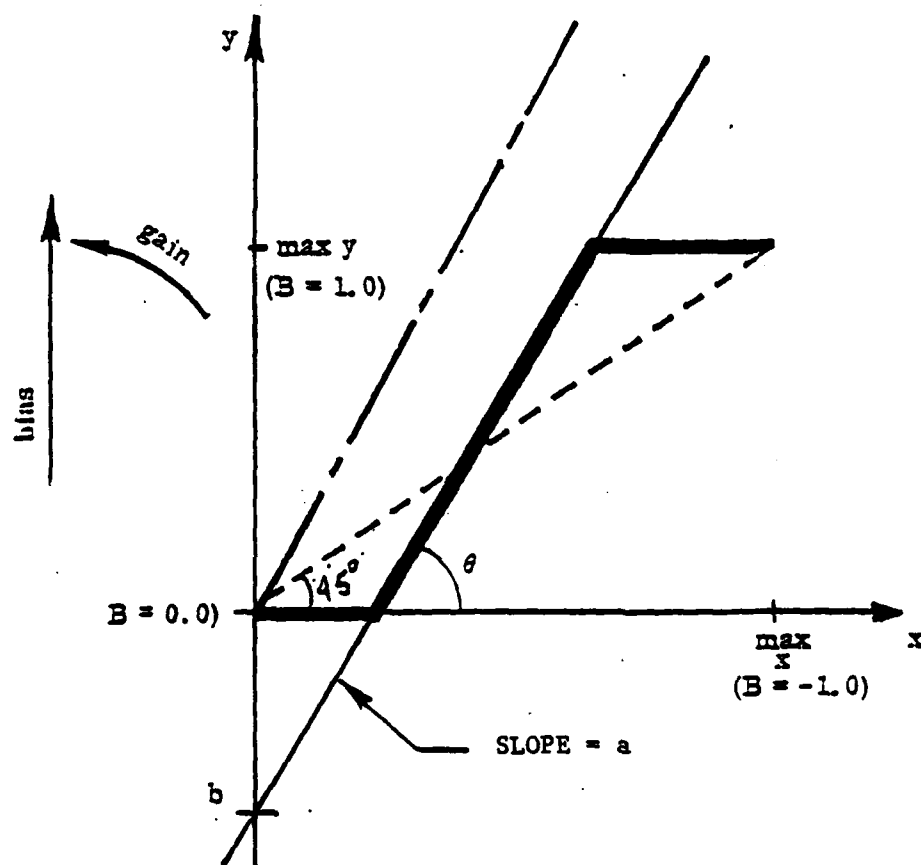
5.2.3.3 Band to Channel Selector

This task interacts with the analyst via the function memories to route any of the six refresh memory video channels to any combination of the three monitor channels (red, green, blue). This task has a dynamic mode, in which a sequence of "time-lapse" displays may be generated. In this mode, the analyst defines the channels to be sequenced, the order of sequencing, color assignment for each channel (one of seven), and the sequencing rates.

5.2.3.4 Contrast Stretch

This task utilizes the function memories to perform a contrast stretch of selected channel(s) of refresh memory. Three modes are provided: linear,

$y = ax + b$, where: y = output signal
 x = input signal
 a = gain = $\tan \theta$, $0^\circ \leq \theta \leq 90^\circ$
 b = bias = $B \times 255$, $B < 0$
 $a \times B \times 255$, $B > 0$



- - - - - $y = x$
 - - - - - $y = ax$
 - - - - - $y = ax + b$

TRANSFER CURVE
 (Clipped to prevent underflow/overflow.)

Figure 5-3. Bias and Gain Computations

histogram equalization, and square root. The first two are based on statistics derived from the selected refresh memory channel. Linear stretching simply expands the range of brightness values to encompass the entire 256 available grey levels without altering the shape of the histogram. Histogram equalization also spans the entire range of grey levels but the histogram shape is modified in the process such that the cumulative distribution function is approximately linear. The square root stretch is not based on channel statistics; it simply modifies the histogram such that the low brightness information is expanded at the expense of the high brightness data.

The basic mathematics for computing the transfer functions, which are in turn loaded into the function memories, are provided in Paragraph 3.5.

5.2.4 GRAPHIC OVERLAYS

Graphics overlays are stored and displayed via the refresh memory theme channels. There are eight one-bit channels. The hardware permits the eight channels to be accessed and displayed as eight independent (non-encoded) channels, or to be encoded into a maximum of 256 channels. Color codes may be assigned by the analyst in either mode of operation.

All tasks which interact with the graphics overlays, or theme channels, are interactive.

5.2.4.1 Annotation

This program allows the user to type alphanumeric text via the keyboard and have it written on a theme channel for display on the CRT.

After initialization, the user selects the destination theme track, and optionally erases the theme track selected. Next, a selection of character size must be made.

The cursor position indicates the location on the screen where the upper left-hand corner of the first character will appear.

5.2.4.2 Theme Color Selector

This task permits the analyst to select color codes for the theme channels in both the encoded and non-encoded modes. Via selection from a previously created color file, the analyst defines red, green, and blue components for each of eight non-encoded themes, the alarm and overlap, or each of sixteen encoded themes.

5.2.4.3 Refresh to Disk - Themes

This task reads user selected themes from refresh memory and writes them on a disk file. Annotation may be included with the file.

5.2.4.4 Disk to Refresh - Themes

This task reads a specified disk theme file and writes the user selected themes to designated theme channels. The previously generated annotation is displayed on the alpha/graphics terminal.

5.2.5 RADIOMETRIC PROCESSING

Radiometric processing tasks include three types of ratioing, contrast stretch and four types of spectral transforms. These tasks are executable in both interactive and batch modes. The array processor is used to perform the

repetitive processing portions of the respective tasks. Entire refresh memory channels, disk files, or censored areas thereof are able to be processed by all radiometric processing tasks. All radiometric processing tasks allow only positive, eight-bit values to be created; overflow and underflow conditions are detected and corrected by clamping to 255 and 0, respectively.

5.2.5.1 Interactive Tasks

All of the following interactive tasks involve a processing dialogue with the analyst followed by the actual processing of the specified data. Processing dialogue is an interaction of the task with the analyst via GDT prompts and analyst responses to select refresh memory channels, scale factors, etc. Data flow in all cases is refresh memory to core to array processor to core to refresh memory.

5.2.5.1.1 Ratio

This task has three modes: ratio, normalize, and difference/sum, performing a spectral ratio of any pair of refresh memory channels. Scale factors may be specified or defaults applied uniformly to all ratio pairs. Mathematically:

$$Y_k = F_k \left(\frac{X_i}{X_j} \right) + B_k$$

where

$i, j, k = 1, 2, \dots, 6$

X_i = Input pixel amplitude for channel i

- Y_k = Output pixel amplitude for channel k
 F_k = Multiplicative scale factor for channel k (default = 128)
 B_k = Bias scale factor for channel k (default = 0)

Normalize mode normalizes channels of refresh memory. Scale factors may be specified or defaults applied uniformly to all normalized channels.

Mathematically:

$$Y_k = F_k \left(\frac{X_i}{\sum X_i} \right) + B_k$$

where

- $i, k = 1, 2, \dots, 6$
 X_i = Input pixel amplitude for channel i
 N = Analyst specified number, $N_{\max} = 6$
 \sum = Summation over N contiguous or non-contiguous channels
 $\sum X_i$
 Y_k = Output pixel amplitude for channel k
 F_k = Multiplicative scale factor for channel k (default = 255)
 B_k = Bias scale factor for channel k (default = 0)

Difference/sum mode ratios the difference and sum respectively of a user specified pair of channels. Up to six such ratios may be specified. Scale factors may be specified or defaults applied to all ratios. Mathematically:

$$Y_k = F_k \left(\frac{X_i - X_j}{X_i + X_j} \right) + B_k,$$

where

$i, j, k = 1, 2, \dots, 6$

X_i = Input pixel amplitude channel i

B_k = Bias scale factor for channel k (default = 128)

Y_k = Output pixel amplitude for channel k

F_k = Multiplicative scale factor for channel k (default = 255)

5.2.5.1.2 Contrast Stretch

This task performs the same computations as the contrast stretch task described under display processing. All three modes are provided: linear, equidistribution, and square root. The differences are that (1) the transfer function tables are stored in the array processor(s) rather than the function memory(s), and that (2) the refresh memory is overwritten with the stretched data. Illustrations and mathematics are provided in Figure 5-3.

5.2.5.1.3 Radiometric Transform

This task has four modes: manual, angle, Hadamard, and eigenvector. Manual transform performs (up to) a six dimensional transform of selected refresh memory channels. The rotation (multiplication) and translation (addition) coefficients are entered by the analyst via keyboard type-ins. Mathematically:

$$\underline{RX} + \underline{T} = \underline{Y}$$

where

X = Input pixel amplitude vector (≤ 6 dimensions)

R = Rotation matrix ($\leq 6 \times 6$)

T = Translation vector (\leq dimensions)

Y = Resultant pixel amplitude vector (≤ 6 dimensions)

Angle transform performs an operation identical to the above, with the exception that the transform coefficients are determined as a function of analyst input rotation angle(s) for selected channel pair(s).

Therefore the transform reduces to a two-dimensional rotation and translation for the two selected channels, p and q:

$$\underline{R}_{p, q} = K \begin{bmatrix} \cos & \sin \\ -\sin & \cos \end{bmatrix} \quad \underline{T}_{p, q} = \begin{bmatrix} t_p \\ t_q \end{bmatrix}$$

where

cos = cosine of input angle

sin = sine of input angle

K = scale factor

t_p, t_q = translation vector coefficients

R_{p, q} = 2 x 2 rotation matrix

The trig functions (matrix coefficients), scale factor K, and translation vector coefficients t_p and t_q are computed as a function of the analyst input angle. They are computed such that maximum utilization is made of the selected two-

space without any overflow or underflow values (the input channels X_p and X_q are assumed to have values spanning the full range of 0 to 255).

The eigenvector transform mode performs a transform on the imagery. Transformation coefficients are derived from the contents of a previously generated training sample statistics file. The parameters of interest are the mean vector, \underline{M} , and covariance matrix, \underline{C} of the selected training sample. The task computes the eigenvectors and eigenvalues from \underline{M} and \underline{C} . The transpose of the matrix of eigenvectors is then scaled and a translation vector computed to guarantee no underflow/overflow values. The resultant rotation matrix \underline{R} and translation vector \underline{T} are then formatted and transmitted to the array processor, which in turn executes the transformation

$$\underline{R}\underline{X} + \underline{T} = \underline{Y}$$

as defined earlier.

The Hadamard transform mode performs both two and four dimensional transforms (analyst choice). The two transforms are defined as:

$$\underline{H}_2 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \quad \underline{H}_4 = 1/2 \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$$

Scale factor K and translation vector T are computed and applied to the selected transform such that the resultant transformation

$$\underline{R_x} + \underline{T} = \underline{y}$$

does not overflow or underflow. The analyst has the capability to manually set K and T; any resulting overflows or underflows are clamped to 255 and 0, respectively.

5.2.5.2 Batch Processing Tasks

All of the batch processing tasks perform the same computations as their interactive processing counterparts. The main difference is that disk files comprise the input and output medium as opposed to refresh memory channels. Data flow, is therefore, disk to core to array processor to core to disk. As with the interactive counterparts, rectangular areas of the designated file(s) may be processed, or the entire file(s) may be processed (analyst choice). Also, all underflow and overflow pixels are detected and clamped to zero and 255, respectively. The tasks include the following.

5.2.6 GEOMETRIC PROCESSING

Geometric processing tasks include skew correction (i.e., Earth rotation

compensation), spatial formatting (zoom, shrink, etc.) and registration. These tasks will be executable in both interactive and batch modes. The array processor is used to perform the repetitive processing portions of the respective tasks. Entire refresh memory channels, disk files, or cursoried areas thereof are able to be processed by all geometric processing tasks. All geometric processing tasks allow only positive, eight-bit values to be created; overflow and underflow conditions are detected and corrected by clamping 255 and 0 respectively.

5.2.6.1 Interactive Tasks

All of the following interactive tasks involve a processing dialogue with the analyst followed by the actual processing of the specified data. Processing dialogue is an interaction of the task with the analyst via GDT prompts and analyst responses to select memory channels, scale factors, etc. Data flow in all cases is refresh memory or disk to core to array processor to core to refresh memory.

5.2.6.1.1 Skew Correction

This function is implemented within the disk to refresh task (paragraph 5.2.2). It corrects for skew in Landsat imagery caused by the Earth's rotation and north-south satellite orbit. The analyst is able to specify the skew angle in degrees via type-in, or to request the program to compute the skew factor as a function of the latitude. This computation is performed as follows: (See Figure 5-4).

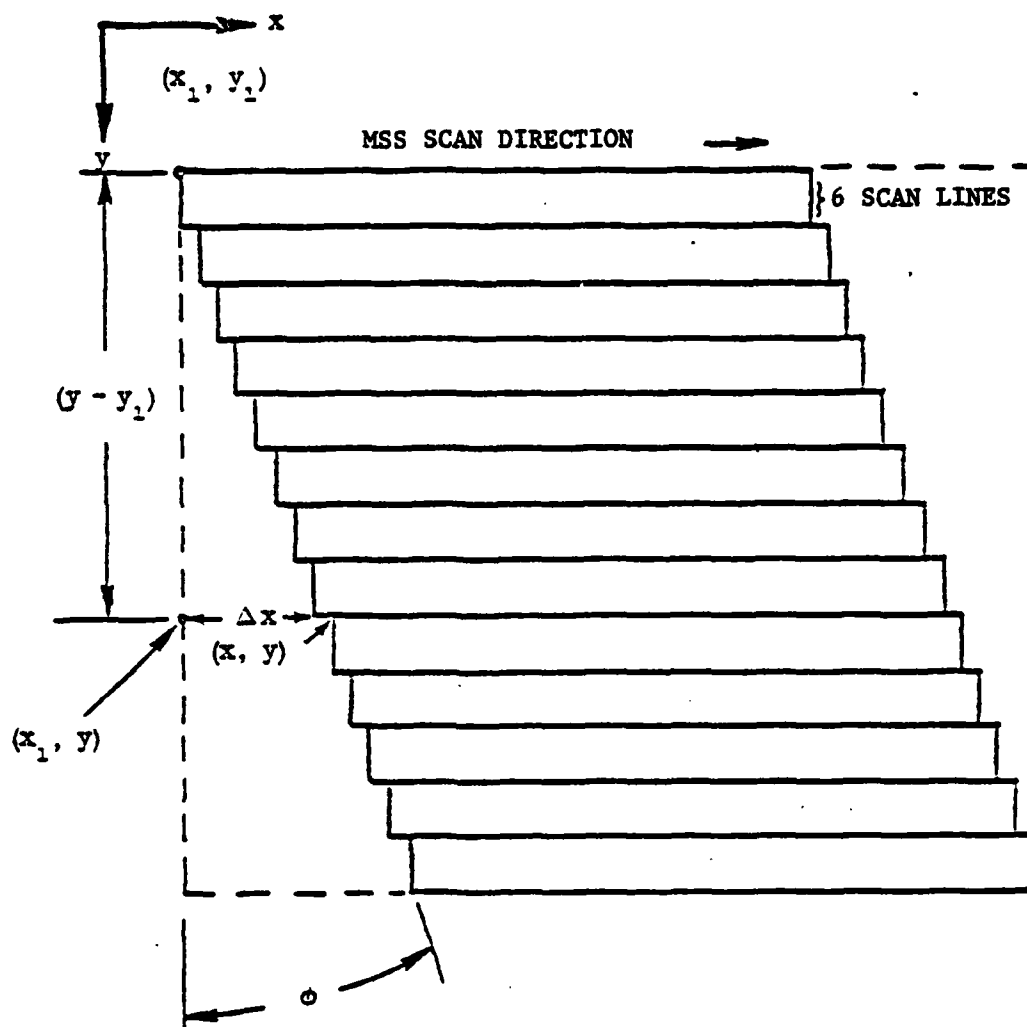


Figure 5-4. Skew Correction

The derivation of x (start pixel number for scan line y) is as follows:

$$\Delta x = (y - y_1) (A) (\tan \phi)$$

where

A = aspect ratio of pixels

ϕ = skew angle

Since six scan lines are recorded simultaneously, the correction is applied to groups of six scan lines together.

Therefore:

$$\Delta x = \text{INT} \left(\frac{y - y_1}{6} \right) \times 6 \times A \times \tan \phi$$

or

$$x = x_1 + \text{INT} \left[\text{INT} \left(\frac{y - y_1}{6} \right) \times 6 \times A \times \tan \phi \right]$$

The skew angle, ϕ , may be derived from the header information as follows:

$$\phi = \cos^{-1} \left(\frac{\cos i}{\cos} \right) - \tan^{-1} \left(\frac{(\cos^2 \theta - \cos^2 i)^{1/2}}{\cos i + \frac{v_r}{v_s} \cos^2 \theta} \right)$$

or ϕ may be specified in degrees by the analyst.

where:

θ = image center latitude

i = orbit inclination (81°)

V_r = rotational velocity at the equator (0.46 km/sec)

V_s = subsatellite point velocity in orbit plane (6.46 km/sec)

5.2.6.1.2 Spatial Formatting

This function is implemented within the task "video, disk to refresh" (paragraph 5.2.2). It performs spatial formatting (scaling), and translation of channel(s) independently in x and y. The process is illustrated in Figure 5-5. The analyst, in response to task prompts, selects the source area via type-in*, then the destination area via type-in or the cursor.

The option is provided to automatically set the mapping parameters per analyst instruction. In the automatic mode, the cursor is set to a square aspect ratio; i.e., the task allows cursor x, y position and x size to be user-controlled, but the y size is forced to the same value as the x size. Furthermore, the analyst may specify the zoom (shrink) factor as a value between 1 and 16. This fixes the output grid (cursor) size, constrained such that it shall not exceed 512 x 512. The position must still be selected by the analyst. A final constraint is that the input (source area) grid minimum size be 4 x 4.

In addition to mapping, this function performs Nearest Neighbor (NN) or Cubic Convolution (CC) resampling (analyst choice). That is, once the destination

*Normally, Scaled Cursor is used to determine source area coordinate.

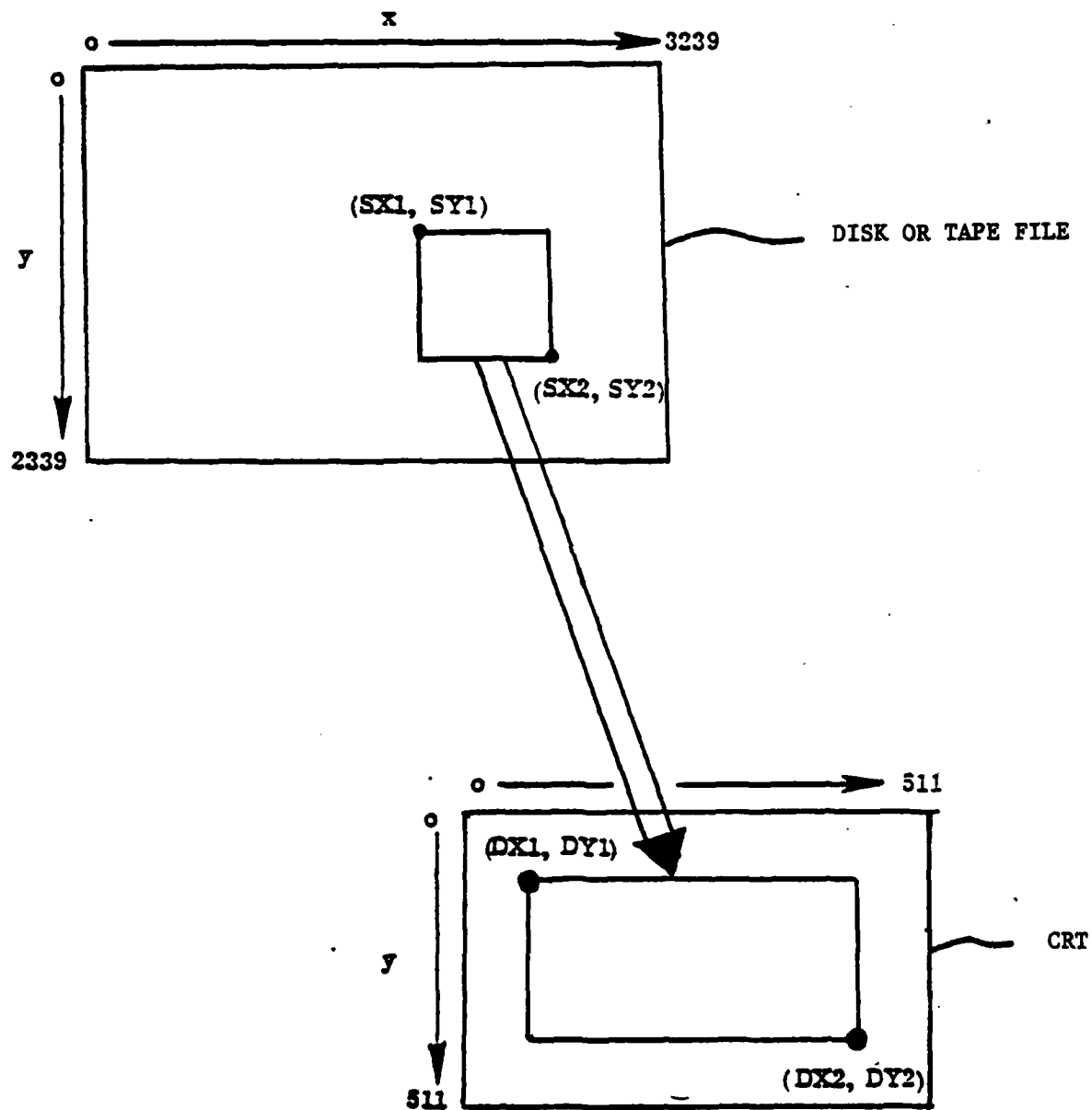


Figure 5-5. Spatial Formatting

area pixel location is mapped from the source area, the pixel intensity value is determined per one of two resampling methods: NN or CC.

NN simply assigns to the selected pixel location the radiometric intensity value of the nearest pixel.

For example, if points A through D in Figure 5-6 represent points in the original input grid, and point E is the point in the output grid to be resampled, the distance from point E to points A through D would be determined and the intensity of the point lying closest to E would be assigned to E. As the figure is drawn, the radiometric intensity value at point D would be the new output value.

With CC, or $\sin x/x$, the resampled output point is computed based on a weighted contribution of neighboring input points. The weighting factors are determined by the cubic approximation of $\sin x/x$, which has the form:

$$\begin{aligned} &= 1-2|x|^2 + |x|^3 & 0 \leq |x| \leq 1 \\ \sin x/x &= 4-8|x| + 5|x|^2 - |x|^3 & 1 < |x| \leq 2 \\ &= 0 & 2 < |x| \end{aligned}$$

The actual application of this function to image resampling is performed as shown in Figure 5-7. If P is the point to be resampled, the cubic $(\sin x)/x$ is applied to points A_1, A_2, A_3, A_4 to obtain A^1 . Points B^1, C^1, D^1 are obtained in a similar manner, and these points are then used in a similar interpolation in the perpendicular direction to obtain point P. Underflow and overflow conditions shall be detected and corrected by clamping to zero and 255,

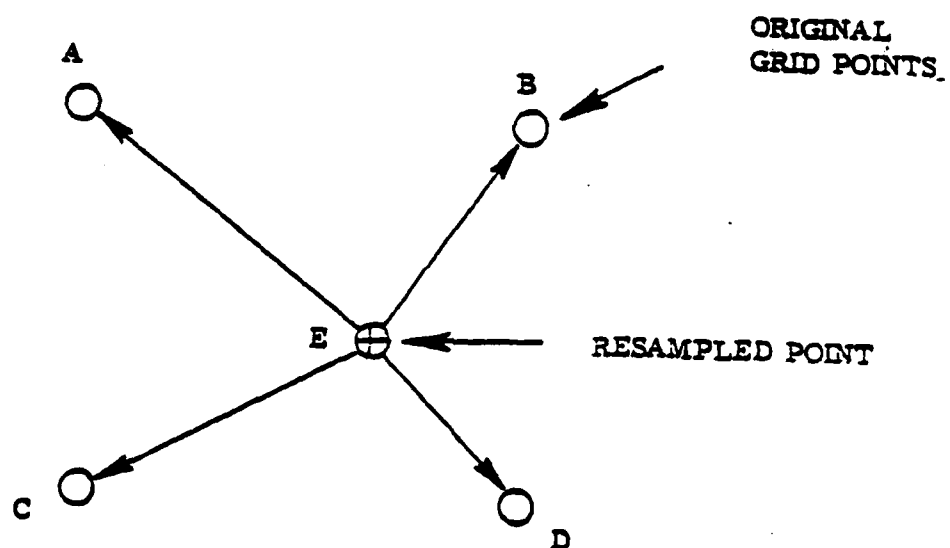


Figure 5-6. Nearest Neighbor Resampling

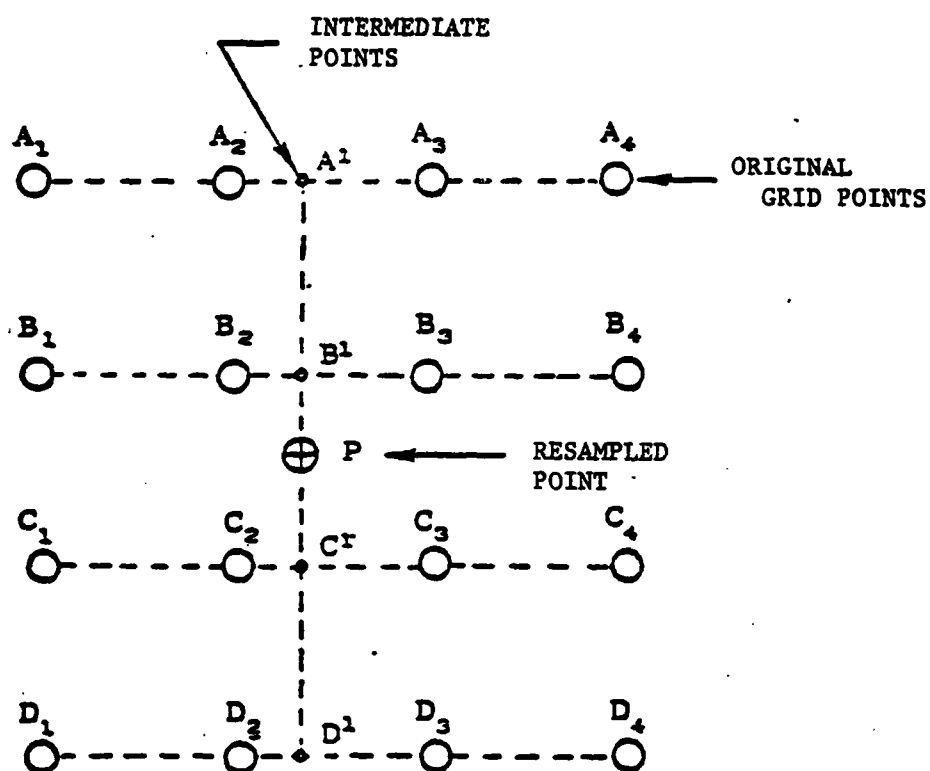


Figure 5-7. Cubic Convolution Resampling

5.2.6.1.3 Registration

This task performs image to image and image to reference grid registration. The analyst specifies the refresh memory channel(s) to be registered, and then three or more Ground Control Points (GCPs).

GCPs are identified via the cursor or analyst input grid coordinates. Following input of the GCPs, the coefficients of the affine transform are determined. The six coefficients of the transform are determined via a least squares fit:

$$\text{Min}_{a_1, b_1, c_1, a_2, b_2, c_2} \sum_{i=1}^N \left\{ (x_i - a_1 u_i - b_1 v_i - c_1)^2 + (y_i - a_2 u_i - b_2 v_i - c_2)^2 \right\}$$

where

N = number of GCPs

(u,v) = location of pixel in output grid

(x,y) = location of pixel in input grid

a_1, b_1, c_1 = affine transform coefficients

The residual errors are then computed and displayed on the GDT for each GCP (with three there are no residual errors). The analyst has the option to delete and/or add GCPs and to recompute the transform coefficients. When satisfied, the analyst initiates processing of the data in the array processor (refresh to core to AP to core to refresh data flow).

The affine transform is defined as:

$$x = a_1u + b_1v + c_1$$

$$y = a_2u + b_2v + c_2$$

where (u,v) represents the location of a point in the output grid and (x,y) represents the corresponding point in the input grid. The transform will translate, rotate, scale and distort; however, no curvature is introduced.

A single channel is processed at a time, since the rotation angle could span a significant number of scan lines. The AP input buffer is sized to accommodate the maximum number of lines at a time. Nearest neighbor resampling is utilized to select the intensity value of the output grid pixel.

5.2.6.2 Batch Processing Tasks

All of the batch processing tasks perform the same computations as their interactive processing counterparts. The main difference is that disk files comprise the input and output medium as opposed to refresh memory channels. Data flow is, therefore, disk to core to array processor to core to disk. As with the interactive counterparts, rectangular areas of the designated file(s) may be processed, or the entire file(s) may be processed (analyst choice). Also, all underflow and overflow pixels are detected and clamped to zero and 255, respectively.

5.2.7 TRAINING AREA DESIGNATION

Two interactive tasks support the designation of training areas: polygon cursor and theme synthesis. Together, they permit the cursor, previous classification

results, polygon bounded areas, or any boolean combination of the above to define homogeneous but not necessarily contiguous training sites. Training site files may be stored on disk for later use. There is no restriction on the number of training files that can be stored.

5.2.7.1 Polygon Cursor

This program provides the capability of generating irregularly shaped themes. These themes may then be used to perform training, boundary definitions, etc. The user is allowed to clear the specified theme before proceeding with the construction of the polygon.

5.2.7.2 Theme Synthesis

This interactive task operates in conjunction with hardware in the console so that a theme may be synthesized by combining two binary images (consisting of the cursor alarm and/or themes) in logical "add", "subtract", "exclusive or", and "and" fashion.

The analyst simply types in the command, the task interprets it, formats it, and transmits it to the console hardware, causing the selected function to occur.

5.2.8 STATISTICS - COMPUTATION/DISPLAY/MODIFICATION

Parametric and nonparametric statistics are derived, displayed to the analyst, modified as necessary, stored on disk, and retrieved as necessary. The files thus created support the Image Classification function.

5.2.8.1 Single Cell Signature Acquisition

This program operates in conjunction with the console and controls to generate

the single cell (1-C) signature. Upon program initiation, the training site must be defined via the cursor and/or a theme. The TA (training area) thus generated should be displayed prior to program execution to verify that the training site is properly selected. The program will properly set the theme synthesizer.

The following parameters are input:

- Channels = any combination of the first four (or less) channels (unique).
- Resolution = number of grey levels per channel, 2 to 256.
Each channel may have a different resolution, as long as it is a binary number (2^N).
- Histogram Rejection Levels = upper and lower bounds of the histogram (measured in area) to be included in the ensuing 1-C signature acquisition.

Five different statistics computed from the one-dimensional histograms of the training site are output for each of the selected channels:

- a. Spectral Bounds - The lower and upper bounds, respectively, assigned by the program such that the area of the histogram (cumulative distribution) between the limits is equal to the percentage defined by the histogram rejection levels. These bounds are expressed in terms of grey levels at the selected effective resolution.
- b. Delta - The inclusive difference between the lower and upper bounds expressed in terms of effective resolution.

- c. Peak - The maximum histogram value expressed in pixels.
- d. Mean - The mean value of the histogram expressed in terms of effective resolution.
- e. Variance - The variance of the histogram expressed in terms of effective resolution.

Three other statistics are measured and/or computed and displayed to the user.

They are:

- a. Training Area - The number of pixels contained within the training site.
- b. Alarmed Area - The number of pixels in the entire scene that fall within the lower and upper bounds defined previously.
- c. Spectral Volume (Cells) - The total number of elemental cells, that are required to completely fill the single cell defined by the lower and upper bounds. This number is computed by multiplying the deltas.

5.2.8.2 Multi-cell Signature Acquisition

This program acquires the multidimensional histogram of the training site, thereby defining the multi-cell (M-C) signature. As in the 1-C signature acquisition, a training area is selected within the program, and the theme synthesizer properly set.

During acquisition, the spectral values of the pixels in the training site are tested against the cells. The acquisition process is made time effective by utilization of a binary search technique, whereby large "empty" regions of spectral space are quickly eliminated. The pixels corresponding to each of the

elemental cells are accumulated, thus defining a multidimensional, or multichannel histogram.

5.2.8.3 Gaussian Statistics Acquisition

This task computes parametric (Gaussian) statistics for a given training sample. The AP is utilized to generate the mean vector and covariance matrix, and uses these parameters to compute the inverse of the covariance matrix, the correlation matrix, and its inverse. These statistics may be given a file name and stored on disk for later retrieval by the Image Classification function. Any number of files may be created. The computations are:

$$(a) \quad M_i = \frac{1}{N} \sum_{P=1}^N X_{iP}$$

$$(b) \quad C_{ij} = \frac{1}{N} \sum_{P=1}^N X_{iP} X_{jP} - M_i M_j$$

$$(c) \quad [C]^{-1}$$

$$(d) \quad \rho_{ij} = \frac{C_{ij}}{(C_{ii} C_{jj})^{1/2}}$$

$$(e) \quad [\rho]^{-1}$$

where

- N = number of training pixels
- M_i = mean value, channel i
- C_{ij} = co-factor channels i and j
- $[C]^{-1}$ = inverse of covariance matrix
- ρ_{ij} = correlation coefficients, channels i and j
- $[P]^{-1}$ = inverse of correlation matrix
- i, j = channels 1, 2, ..., 6
- SF = scale factor = $(255)^2$

At the completion of processing, the parameters are displayed on the GDT.

5.2.8.4 One-Dimensional Histogram Display/Modification

This program displays the histograms resulting from a previous single-cell acquisition in graphic format. As an option the operator may modify the single cell alarm by altering the individual channel upper and/or lower limits which are also displayed.

The display actions consist of:

- a. An overview histogram for all channels
- b. One selected channel at a time; modify the established upper and/or lower limits for the displayed channel.

The program allows the user to modify limits so that a desired portion of the histogram is truncated.

5.2.3.5 Two-Dimensional Histogram Display/Modification

This program is an extension of the one-dimensional histogram display to a second dimension. Histograms are computed and displayed as cluster plots of two selected channels from a specified M-C signature acquisition file.

Upon entry, the operator must enter the two channels to be crossplotted and the name of the stored multicell signature to be displayed.

The cluster plot of Figure 5-8 depicts channels 3 and 4 in the systems. As indicated, channel 3 corresponds to the Y axis and channel 4 corresponds to the X axis; the X and Y axis represent gray levels and the size of the plotted cells is indicative of the frequency of occurrence. The larger the cell, the more frequently it occurred within the training area. The resolution used is the resolution used by the referenced M-C signature acquisition task.

Two complete scans are performed; the first scan is made in order to identify the cell(s) with maximum density, the second scan locates the occupied cells and positions them in the appropriate place on the crossplot.

The square representing the maximum density cell is scaled to occupy the full cell area. Cells with lesser densities are drawn proportionally smaller giving the impression of cell population on the display.

When the projection is completed, the operator is allowed to designate bounds: top, bottom, left and right, by using the cursors. These bounds, defining a monocell signature, can be drawn on the display; the limit registers in the console are simultaneously set, allowing the enclosed cells to be mapped by the alarm. The alarm obtained by this method can then be loaded onto a theme.

2-D PROJECTION
CH3(Y) VS CH4(X)

(L)EFT, (R)IGHT
(T)OP, (B)OTTOM
(D)RAW.

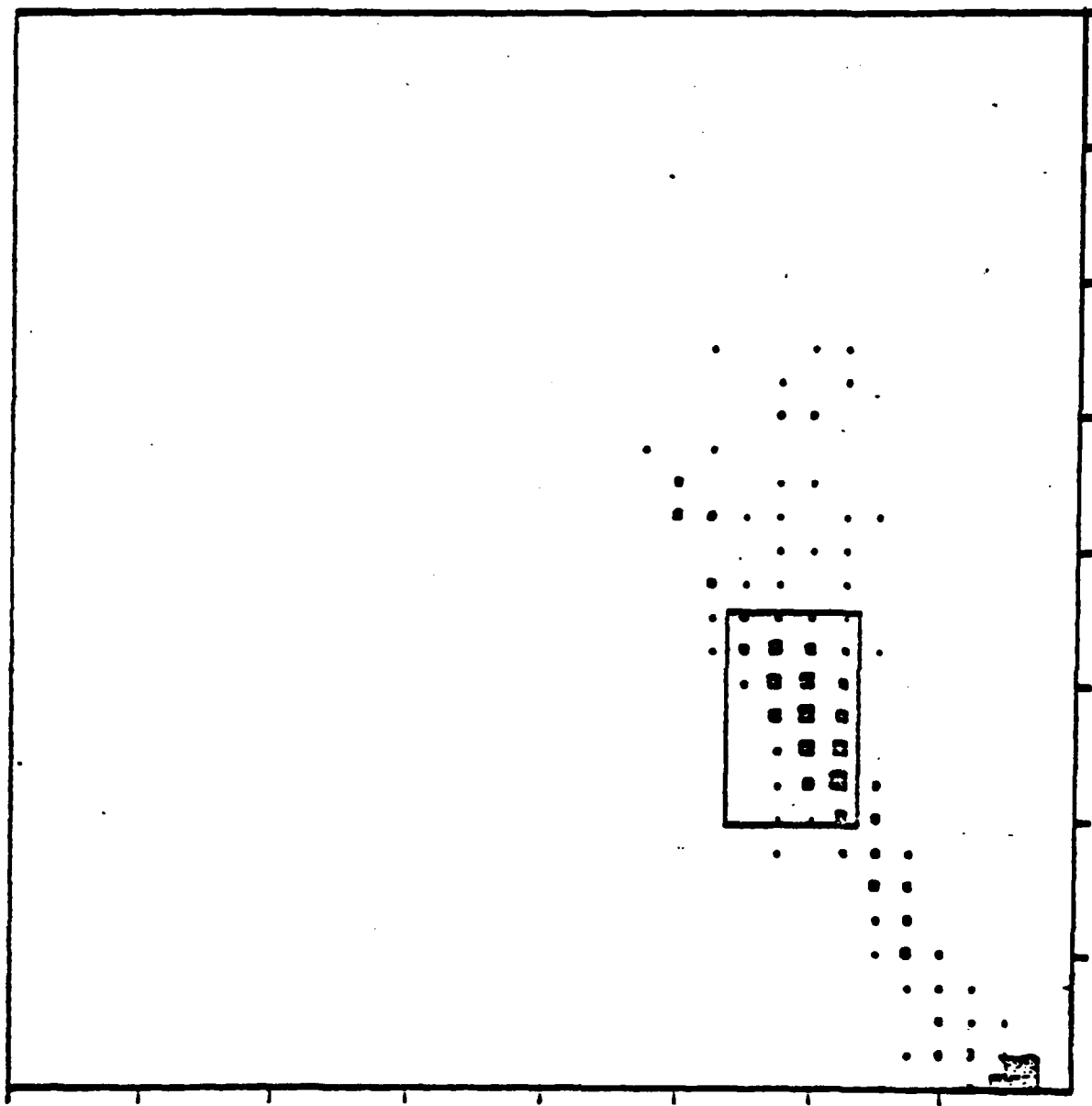


Figure 5-8. Histogram Display/Modification

5.2.8.6 Main Cell Cross Reference

This program retrieves a multicell signature file generated during a previous multicell signature acquisition, ranks the cells contained within the signature and displays the most populated cells on the printer/plotter and GDT. In this fashion the user is able to obtain hard copies of any or all of his signature files in a tabular form.

5.2.8.7 Gaussian Statistics Display/Modification

This task displays and modifies a previously generated Gaussian statistics file. Upon entry, the analyst specifies a Gaussian statistics file name; the file is read from disk, formatted, and displayed on the GDT. The following parameters are displayed:

- a. Mean vector (M)
- b. Covariance matrix (C)
- c. C⁻¹
- d. Correlation matrix (P)
- e. P⁻¹

together with the file name, resolution, annotation, etc.

The analyst is then presented with the option of modifying the statistics. Specifically, the analyst may modify any or all of the terms in the mean vector M and covariance matrix C. Upon completion, the new C⁻¹, and P, P⁻¹ are computed and displayed on the GDT.

5.2.8.8 Thresholding

This program performs classification of the video data contained in the refresh memory based on the signature file acquired during a previous multicell signature acquisition. The signature is tested, cell-by-cell, against the user's selected threshold (default threshold is one). This means that if the pixel count for a given cell is greater than or equal to the threshold value, it is retained; if less, it is ignored. For example, a threshold of one would cause all "empty cells" to be discarded.

5.2.8.9 Semisupervised Clustering

This task clusters imagery via a migrating means method. The analyst specifies the following upon entry:

- a. Area to be clustered via the cursor and/or a theme track.
- b. Channels to be utilized
- c. Cluster seeds (centroids, means) one vector per category.

If seeds are not specified, the task computes the seeds by:

- a. Spanning the N-dimensional feature space with a diagonal, and
- b. Dividing the diagonal into $K + 1$ equal intervals, leaving the K nodes as the cluster seeds (K is the number of clusters).

Processing in the AP may be summarized as follows:

- a. The pixels in the specified clustering area are assigned, pixel by pixel, to one of the cluster seeds, based on a minimum Euclidean distance test (described below).
- b. Once all pixels have been assigned to seeds, new cluster centroids are computed.

- c. The process now repeats, the test area pixels are reassigned to the closest of the updated centroids, and centroids are once again recomputed (thus the term migrating means).
- d. The clustering process continues until the centroids converge (i.e., no change between successive passes), until manually stopped by the analyst, or until a preset number of passes have been executed.

Eclidean distance test:

$$\text{Min}_k \sum_{n=1}^N \left[(X_{nk} - M_{nk})^2 \right]$$

where

- k = Class designator ($k_{\max} = 16$)
- X_n = Pixel amplitude in n^{th} channel
- M_n = Mean (centroid, seed) of n^{th} channel
- N = Number of channels ($N_{\max} = 6$)

The analyst has the option to save the clusters in a file before exiting.

5.2.8.10 Cluster Display/Modification

This task provides the facility to read, display and modify a previously created cluster centroid file.

5.2.9 IMAGE CLASSIFICATION

Both supervised and nonsupervised classification functions are available to the analyst. The Maximum Likelihood Classifier accesses previously generated signature statistics, and is thus a supervised classifier. The categorization of pixels into one of sixteen classes is based on the probability of occurrence as determined by the spectral intensity distributions acquired during signature statistics acquisition (parameteric or non-parametric).

A minimum distance classifier may also be provided. It is nonsupervised in the sense that signature statistics are not a prerequisite; the process simply partitions the spectral space of a selected section of an image into a user specified number of spectrally homogeneous regions, or clusters.

Both supervised and semisupervised classifications are performed over the entire frame in batch mode, or selected test scenes interactively. Another interactive mode utilizes the moving window to display classification results as they are generated, a line at a time, over the entire frame.

5.2.9.1 Interactive Tasks

Three interactive tasks are provided: Non-parametric Maximum Likelihood, Parametric (Gaussian) Maximum Likelihood, and Minimum Distance Classification. All involve a processing dialogue, followed by computation to determine AP

parameters, and finally the execution of the processing loop; refresh to core to AP to core to refresh. The result of the processing is a classification map-encoded themes-stored in channel six of the refresh memory. Color codes for each the categories must have been preloaded into the theme color memories.

5.2.9.1.1 Non-Parametric Maximum Likelihood

This task classifies up to four channel imagery into categories based on the normalized histograms for each class. The analyst specifies the following input parameters upon entry:

- a. File names on the input files; all must have the same dimensionality N.
- b. Position of the cursor around the area to be classified on the CRT (or specifies the entire screen).
- c. Channels to be utilized for classification (must total N).

The program then retrieves the signature files from disk, and verifies that dimensionality and resolution are common. Any files that do not meet this criteria are rejected. The task then normalizes each of the files against their respective training sites; i.e., the pixel counts are divided by the number of pixels in the respective training samples. The normalized files are now compared, cell by cell; any cells in common with more than one category are detected. These conflict cells are then compared on the basis of normalized pixel count, and the signature files modified in favor of the highest count. That is, the cell in the signature files with less than the maximum count is deleted from those files. This process continues for all conflict cells until all conflicts have been resolved.

At this point a cell table is created with ≤ 8192 entries. Each entry in the cell table is a code word of eight bits that identifies the category that the cell belongs to (or no category). This table is then loaded into the AP memory. The table look-up program is retrieved from disk and loaded into the AP program memory, and classification commences; refresh (encoded themes). The censored area (or entire screen) is classified. The number of pixels assigned to each category is accumulated, and reported on the terminal at termination. All eight bits are carried from the table to the refresh memory, even though only five are required (16 categories or no category) to simplify and speed up operations. The table is accessed by subtracting the minimums, stripping the most-significant bits (MSBs) from the remainder of each of the four channel pixels and packing them into one word (13 bits maximum). The number of MSBs (M_i 's) from each channel byte is computed as follows:

$$M_i = \text{INT} (\log_2 [\max_i - \min_i]) + 1 \quad \sum_i M_i \leq 13$$

where

MAX_i = Maximum gray level found in all MC files for channel i
expressed in terms of the resolution for that channel

MIN_i = Minimum gray level found in all MC files for channel i
expressed in terms of the resolution for that channel

i = Channel index

EXAMPLE:

Let

$$\text{MIN}_1 = 2 \quad \text{MIN}_2 = 8 \quad \text{MIN}_3 = 8 \quad \text{MIN}_4 = 35$$

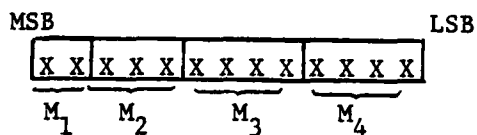
$$\text{MAX}_1 = 4 \quad \text{MAX}_2 = 13 \quad \text{MAX}_3 = 22 \quad \text{MAX}_4 = 50$$

$$R_1 = 8 \quad R_2 = 16 \quad R_3 = 32 \quad R_4 = 64$$

Then

$$M_1 = 2, \quad M_2 = 3, \quad M_3 = 4, \quad M_4 = 4$$

The table address then becomes:



5.2.9.1.2 Parametric Maximum Likelihood

This task classifies imagery into categories based on the parametric (Gaussian) maximum likelihood decision rule. The analyst specifies the following input parameters upon entry:

- a. File names of the Gaussian statistics files
- b. Assignment of categories to color codes
- c. Positions the cursor (rectangle mode) around the area to be classified on the CRT (or specifies the entire screen)

d. Null class threshold.

e. Channels to be utilized for classification; any combination of channels provided that the total dimensionality matches the dimensionality of the selected statistics files.

The program then retrieves the specified statistic files from disk, and verifies that dimensionality is common. Any files not meeting this criteria are rejected.

Lower triangular rotation matrices $\underline{\underline{R}}$ are then computed from each of the respective covariance matrices $\underline{\underline{C}}$ via Cholesky Decomposition. Approximately half the number of multiples and adds is saved by decomposing $\underline{\underline{C}}$ into the lower triangular $\underline{\underline{R}}$'s where $\underline{\underline{R}}\underline{\underline{R}}^T = \underline{\underline{C}}$.

The program then loads the $\underline{\underline{R}}$'s, μ , and null threshold into the AP table memory and the appropriate AP task is read from disk and loaded into program memory.

Processing then commences: refresh (video) to core to AP to core to refresh (encoded themes). The cursored area (or entire screen) is classified, one eight-bit code word per pixel position. The number of pixels assigned to each category is accumulated, and reported on the terminal at task termination.

The classification algorithm, executed in the AP, is shown below:

$$\underline{\underline{Y}}_k = \underline{\underline{X}} - \underline{\underline{\mu}}_k \quad (\text{Translate}) \quad (1)$$

$$\underline{\underline{Z}}_k = \underline{\underline{R}}_k \underline{\underline{Y}}_k \quad (\text{Rotate}) \quad (2)$$

$$Q_k = \underline{\underline{Z}}_k^T \underline{\underline{Z}}_k \quad (\text{Sum of Squares}) \quad (3)$$

$$\text{IF : } Q_1 \leq W_{k1} + Q_k \text{ for all } 1 \neq k, \text{ then: } \underline{\underline{X}} \rightarrow 1 \quad (4)$$

$$\text{IF : } Q_1 > T, \text{ then: } \underline{\underline{X}} \rightarrow \text{null category} \quad (5)$$

Processing in the AP then commences; the Euclidean distance measure is used to assign pixels to centroids:

$$\text{Min}_k \left[\sum_{n=1}^M (X_{nk} - M_{nk})^2 \right]$$

where

k = class designator ($k_{\text{max}} = 16$)

X_n = pixel amplitude in n^{th} channel

M_n = mean (centroid) of n^{th} channel

N = number of channels ($N_{\text{max}} = 6$)

The minimum distance is then compared to the threshold value; if greater, the pixel is assigned to the null category.

The specified classification area is classified by passing the data through the minimum Euclidean distance operator and storing the resultant thematic maps in the refresh memory for display and evaluation. The number of pixels assigned to each category is accumulated, and reported on the terminal, along with steady-state means at task termination.

The analyst has the option to save the classification results on disk before exiting.

5.2.9.2 Batch Processing Tasks

The batch versions of the three classification functions operate the same as their interactive counterparts, with the exception that disk files are used instead of refresh memory. Data flow is disk (video) to core to AP to core to disk (encoded themes).

5.2.10 DATA RECORDING

These tasks permit the recording of disk files on tape or the printer/plotter. Two tasks comprise data recording - both are batch. Theme Print prints out classification maps on the printer/plotter. Session Preserve saves the contents of a session on tape.

5.2.10.1 Theme Print

This task accesses the previously generated parameter file containing the following information:

- a. Name of classification file.
- b. Alphanumeric or halftone symbol assignment, one per theme
- c. One line of annotation per symbol
- d. Title (one line of text)
- e. File window to be printed
- f. Matrix size (8 x 8 or 16 x 16).

When initiated, this task accesses the specified disk classification file, formats it, and prints it on the printer/plotter.

Different classes are represented by the previously defined symbols. The previously defined titles are printed at the top of the printout. The data is

bounded by a border and annotated with pixel column and line numbers. A list of theme/symbol assignments together with the previously entered annotation is also printed for reference purposes. Since a maximum of 128 pixels is printed per line (8 x 8 matrix case), wider areas are printed in segments.

This task utilizes the printer/plotter in a square (nonstandard) mode such that class symbols are printed with 1:1 aspect ratio, thus preserving geometric fidelity.

5.2.10.2 Session Preserve and Session Restore

The batch Session Preserve task saves user specified files on tape. Any or all files having the specified session number are preservable. The companion Session Restore task is able to read the files and return them to disk.

5.2.11 UTILITY

Four utility tasks are provided to support the various image processing functions. Pseudo image file, the only batch utility, creates a disk image file from a disk classification file. False color study provides a means to generate and select colors for application to programs which later utilize color coding. Theme totalizer simply reads the theme counters in the console and reports the results to the analyst via the GDT. Finally, refresh to disk stores the refresh memory contents on disk as an image file.

5.2.11.1 Interactive Tasks

The interactive tasks include false color study, theme totalizer, and refresh to disk.

5.2.11.1.1 False Color Study

This task provides the means to generate and select color chips, and to create a disk file(s) of chip codes for later access by application programs (e.g., pseudo image file).

The theme color memories are loaded with the appropriate tables to convert the codes for each chip into RGB components thus creating uniform colors within each chip.

5.2.11.1.2 Theme Totalizer

Upon initiation this program reads the theme totalizer in the console, which are the digital counts of the themes, the alarm, and the alarm gate. They are expressed in TV element counts as well as percent of the display area and output to the graphics terminal.

The percentages are determined by dividing by the total screen area (512 by 512), or by a user input area value. Default is 512 by 512.

5.2.11.2 Refresh to Disk

This task reads video data from any or all refresh memory channels and saves it on disk as an image file.

5.2.11.3 Pseudo Image File

This task accesses a previously generated parameter file containing the following information:

- a. Classification file to be read.
- b. File created by the false color study task.
- c. Output image file name.

5.2.12 CONSOLE DIAGNOSTICS

These Interactive Tasks provide console diagnostics. Included are:

- a. Test patterns
- b. Densitometer
- c. Exercise
- d. 1-D histogram data list
- e. N-D histogram data list.

5.2.12.1 Test Patterns

Test patterns allow data to be written into the refresh memory in one of six patterns. These patterns exercise the full dynamic range of the refresh memory and provide a quick look diagnostic capability.

5.2.12.2 Densitometer

Densitometer displays the gray level values from refresh memory scanline (or column) identified by the cursor as a plot of intensity versus X position on the GDT.

5.2.12.3 Exercise

This diagnostic program allows the operator to exercise all console functions that are interfaced to the computer.

The following may be exercised:

- a. Video transfer to and from all six channels of the refresh memory.
- b. Theme transfer to and from all eight theme channels of the refresh memory

- c. Cursor X, Y (position and $\Delta X, \Delta Y$ (size) read/write capability
- d. Set the spectral limit setting of any or all channels, either single cell or multicell modes (1-D or N-D modes)
- e. Read histogram counters (1-D or N-D modes)
- f. Read totalizers
- g. Read video, panel switches:
 - 1. Attention
 - 2. Cursor mode (rectangle, rotated rectangle, crosshair)
- h. Read/write function memory contents, controls.

Repetitive looping is an option on all transfers to aid in troubleshooting.

5.2.12.4 1-D Histogram Data List

This program displays on the GDT the numerical histogram data acquired during a previous single-cell signature acquisition. The listing in a tabular form consists of the number of pixels per gray level for each of the N-channels.

5.2.12.5 N-D Histogram Data List

This task displays the contents of the specified M-C signature acquisition file.

SECTION 6

SYSTEM CONSIDERATIONS

Previous sections of this report have discussed the analytical requirements of an image analysis system (Section 3), the capabilities of available hardware (Section 4) and a typical software structure (Section 5). The purpose of this section is to show how the various hardware and software elements may be combined into a system that will satisfy the stated requirements, both in analytical capability and in the application and performance needs of the Corps of Engineers. The manner in which this is demonstrated here is by presenting a discussion of three principal areas of concern. First, a discussion of applicable system architectures at a gross level presents alternative approaches to the problem of developing an image analysis capability for a large, widespread agency with diversified interests such as the Corps of Engineers. Second, a discussion of the specific characteristics of a typical image analysis terminal provides a description of a basic hardware/software system that can be used as an example of a "baseline" design concept. This discussion also shows how the basic system concept is fundamental to the three architectures presented, and how the different approaches may be synthesized from it.

The third portion of this section provides a discussion of (and candidate solutions and tradeoff parameters for) the key system problem area of inter-processor communications; reduction of terminal-to-processor data transfers; and the issues involved in the partitioning of functions between special purpose hardware, host-processor and special purpose processor (array processor) implementations.

6.1 SYSTEM CONCEPTS

Of the many possible configurations that might meet the needs of the COE for

access to and manipulation of TM data, three generic concepts were selected for detailed analysis. These are:

- a. Multiple independent systems
- b. Collocated multiterminal system
- c. Distributed multiterminal system.

The apparent diversity of these concepts was a primary consideration in their selection, although, as will be seen, they are not as different as might be expected from their names.

The basic capabilities that must be provided by any viable system are:

- a. Accept TM data, on HDT and CCT
- b. House and maintain TM data archive
- c. House and maintain data base(s)
- d. Perform bulk processing (classifications, etc.)
- e. Permit hands-on data manipulation
- f. Generate output products.

In the following three sections a general overview of each concept is presented, including basic system description, major options, system configuration, operational mode, advantages and disadvantages, and general comments. These are followed by a brief comparison of the three concepts. Specific issues identified in these discussions are examined in detail in later sections of this report.

In the following sections the term "interactive terminal" refers to an image display, a keyboard, and an alphanumeric/graphic display, that can be separate or integrated units. Interactive terminal capabilities can vary from the so-called "dumb terminal" where nearly all information processing is handled by the

CPU, including the most routine tasks, to the so-called "intelligent terminal" which usually contains microprocessors and can be programmed to handle complex tasks and often includes large amounts of storage. The capabilities of the interactive terminals have a significant impact on the storage and processing that must be provided by the CPU.

6.1.1 MULTIPLE INDEPENDENT SYSTEMS

Using this concept, the Corps of Engineers would install independent image analysis capabilities at a Laboratory, Division or District level. Each system would provide the complete capability required by the local organization. In this context, an image analysis system would typically consist of:

- a. One or more interactive operator terminals, each with access to all or a portion of a large block of refresh memory
- b. A host processor (typically a minicomputer) with an appropriate amount of online disk storage, CCT I/O devices and line printer/graphic plotter devices
- c. An array processor under the control of the host processor
- d. A film scanner/recorder, possibly as a standalone unit, or attached to the host processor and driven directly from it.

A block diagram of such a system is shown in Figure 6-1.

Some advantages of this type of concept are:

- a. Basic facility commonality will permit transfer of new software and techniques between facilities as required.
- b. Each facility can be customized to best satisfy the needs of its region (data volume, project types, analysis methods).
- c. Operators will become familiar with regional problems and projects.
- d. The end user of the data can remain close to his particular problem areas and be more closely involved in the data analysis procedures.

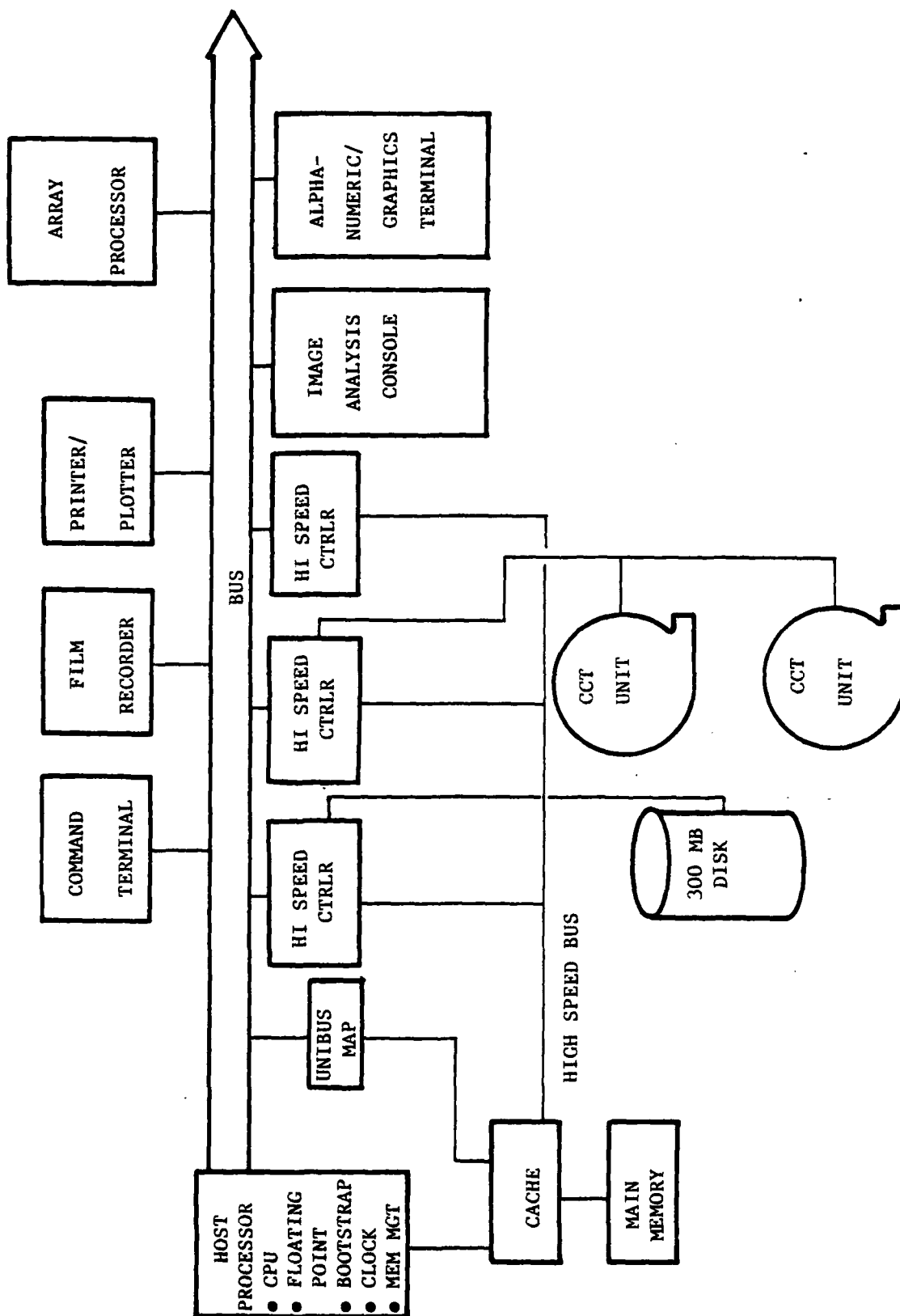


Figure 6-1. Standalone System Configuration

There are, however, disadvantages:

- a. There is a large amount of hardware duplication. Money saving efforts may result in reduced capabilities.
- b. A large number of personnel will be required to operate these independent facilities, with the implication of an extensive training requirement.
- c. The absence of communication links between facilities could hinder dissemination of new software and techniques and cooperative problem solving.
- d. Input data handling will be a problem area: either each facility will need HDT recorders, or CCTs will have to be shipped from a central preprocessor, with consequent delays in receipt by the local facility.

6.1.2 COLLOCATED MULTITERMINAL SYSTEM

This concept consists of a single large facility that has all the capabilities required to generate user requested products from the basic input data. Interactive terminals, input/output devices, main data bases and central archives will all be collocated at a central facility. The actual architecture will depend on the number of terminals, the variety of output devices, the volume of data processed, and the sophistication of the processing algorithm. Typically, however, such a system would incorporate a large mainframe computer or one of the new generation of 32-bit minicomputers as a host processor, with several satellite terminals. A centralized storage capacity for a large number of Landsat-D scenes will be accessed by the host processor, and data ingest may be from high density tapes as well as CCT and film scanners. Data I/O resources and high speed processing devices, such as array processors, will be implemented

AD-A091 959

GENERAL ELECTRIC CO LANHAM MD SPACE DIV

F/6 22/2

ADVANCED SATELLITE HARDWARE/SOFTWARE SYSTEM STUDY.(U)

APR 80 R SPENCER, R HO, F KABAT, D M SMITH

DAAK70-79-C-0009

UNCLASSIFIED

A0SD54213

ETL-0225

NL

3 x 3

410-6

79-300



END

DATE

FILMED

1-81

DTIC

as part of the host processor and used as required by the satellite terminals.

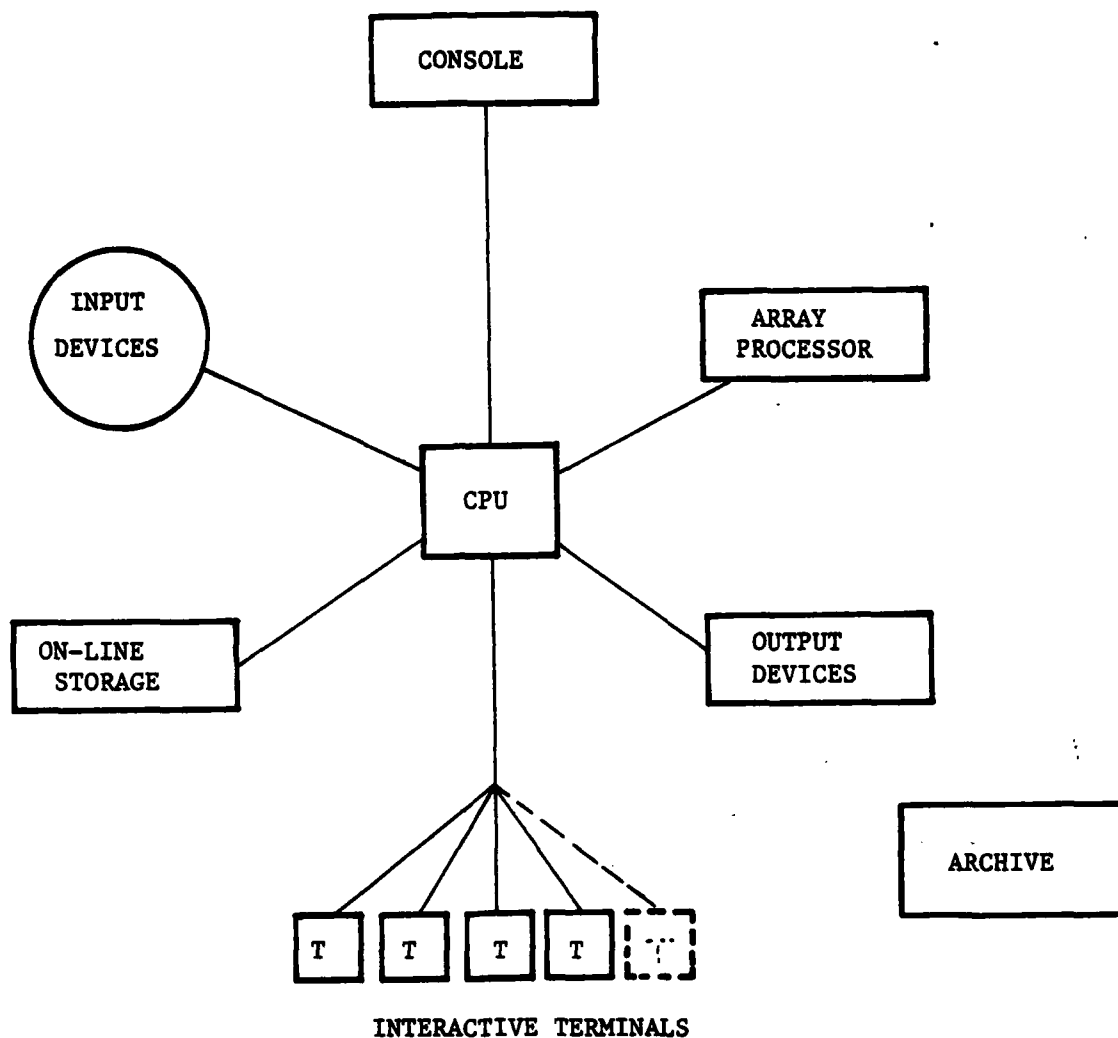
Figure 6-2 shows a typical configuration for a centralized system.

Such a system has features that are advantageous to a user like the Corps of Engineers:

- a. Such a system could be used either as a central facility for all COE requirements or implemented as a set of regional facilities.
- b. A centralized system would support the capabilities of a large archive based on HDT products.
- c. Data dissemination from NASA would be simplified by virtue of the fact that a limited number of shipping destinations would be involved and coverage of the areas of interest (whole US or specific region) may be provided routinely.
- d. The system could be used very efficiently, with a high utilization factor since little duplication of capability or excess capacity would exist in a properly sized system.
- e. Expansion of capabilities could be accomplished by the addition of extra terminals.
- f. Upgrading of software capabilities would automatically provide an upgrade for all terminals.

There are, however, significant disadvantages:

- a. The operator is not dealing with data representing "local" projects and thus loses the benefit of familiarity with local requirements.
- b. The scheduling of requests for analysis may become a problem, with slow responses developing due to processing backlog or the presence of higher priority activities.
- c. User interaction with his data analysis will be awkward, involving considerable lost time and travel to and from the processing facility.



EXAMPLES OF OUTPUT DEVICES: PRINTER, PLOTTER, FILM RECORDER, CCT RECORDER

SOME OUTPUT DEVICES NEED NOT BE DIRECTLY CONNECTED TO THE SYSTEM (E.G. A FILM RECORDER COULD BE A STAND-ALONE UNIT ACCEPTING CCTS AS INPUT)

Figure 6-2. Collocated Multi-Terminal System

- d. As the capabilities of the terminal are enhanced to offload the host processor from performing simple, straightforward tasks, the terminal tends to become as complex as the standalone system, with none of its advantages.

6.1.3 DISTRIBUTED MULTITERMINAL SYSTEM

This concept consists of a single central facility and many remote sites connected to it via communication links. Each remote site could have a different hardware complement and varying capabilities. As such, the configuration represents a compromise between the standalone terminal concept and the collocated system concept.

A major problem area with this concept is, however, the requirement for communications between the host (central) facility and the remote terminals.

If this communication link is minimized, then the capabilities of the remote terminals must be enhanced, particularly in the area of I/O capacity. A high speed link, capable of transferring large volumes of data into refresh memory, will be expensive and will not necessarily negate the requirement for local output devices such as CCT drives, film recorders, etc. (This issue will be discussed in more detail in paragraph 6.3.)

6.1.4 COMPARISON OF CONCEPTS

The three concepts presented have considerable similarities despite the different configurations. Thus, the two multiterminal concepts differ primarily in the degree of tightness of communication between the host and terminal system. As the capabilities of the terminal are enhanced to satisfy the requirement for alleviating the load on the shared resources and/or

communications links, the terminal capabilities approach those of the standalone independent system.

6.2 INTERACTIVE TERMINAL DESIGN

Paragraph 6.1 discussed the architecture of multiterminal image analysis systems, and introduced the concept of a spectrum of designs, ranging from a system with little capability other than display functions at the terminal to a system where each terminal functions as a standalone device for the bulk of its operation.

Within this range of capabilities, however, there are certain basic requirements for a minimum display terminal configuration. Enhancements to the capabilities of this basic configuration may be provided by the addition of special purpose hardware, by the incorporation of local I/O devices, or by the enhancement of the capabilities of the local control processor and its associated applications software.

In this section the basic requirements for the interactive terminal are described. Further discussions introduce the enhancements achievable, by describing the tradeoffs to be performed in selecting special purpose hardware vs. software implementations, and the way in which special purpose hardware may be implemented in the terminal system.

6.2.1 BASIC IMAGE ANALYSIS TERMINAL CONFIGURATION

Although the concept of a basic terminal configuration that relies entirely on external processor capability for all functions, including basic control, has been introduced (the "dumb terminal" concept) such a design is inadequate for any practical image analysis activities. Thus, the basic terminal concept that will be described here is one that provides a degree of autonomy in display

control, but requires attachment to a host processor for data I/O and for applications related processing by access to appropriate software packages. A simplified block diagram of such a terminal is shown in Figure 6-3.

This configuration uses a microprocessor (or a small minicomputer) system to provide localized control for all elements of the terminal, and to act as an interface controller to permit data to flow from the host system and operator commands to flow to the host. This type of architecture permits a single (bidirectional) interface to the host. A simpler design could eliminate the microprocessor but would involve more interrupts of the host and would require several more independent interfaces.

The microprocessor system consists of a microprocessor, associated memory and a simple storage device (floppy disk or tape cartridge) for operating system and diagnostic software loading.

Refresh Memory is loaded from the host computer through the computer interface. Refresh memory is typically provided in blocks of 512 x 512 x 8 bit blocks, and is addressed in eight bit bytes for image data. Sufficient channels of refresh memory are provided to handle the full number of Landsat bands (four for Landsat 1, 2, 3, seven for Landsat-D). An additional channel is provided for use as a theme overlay channel - this channel is addressed on a bit-by-bit basis to provide the capacity for generating up to eight theme overlays. Note that, although memory is provided in 512 x 512 byte blocks, larger quantities can be supplied (up to 4096 x 4096 bytes for some manufacturers).

In the simple terminal described here a set of three channel selector boards, controlled by the microprocessor, routes data from the refresh memory channel to each of the three (red, blue, green) channels for the display. Thus, any band

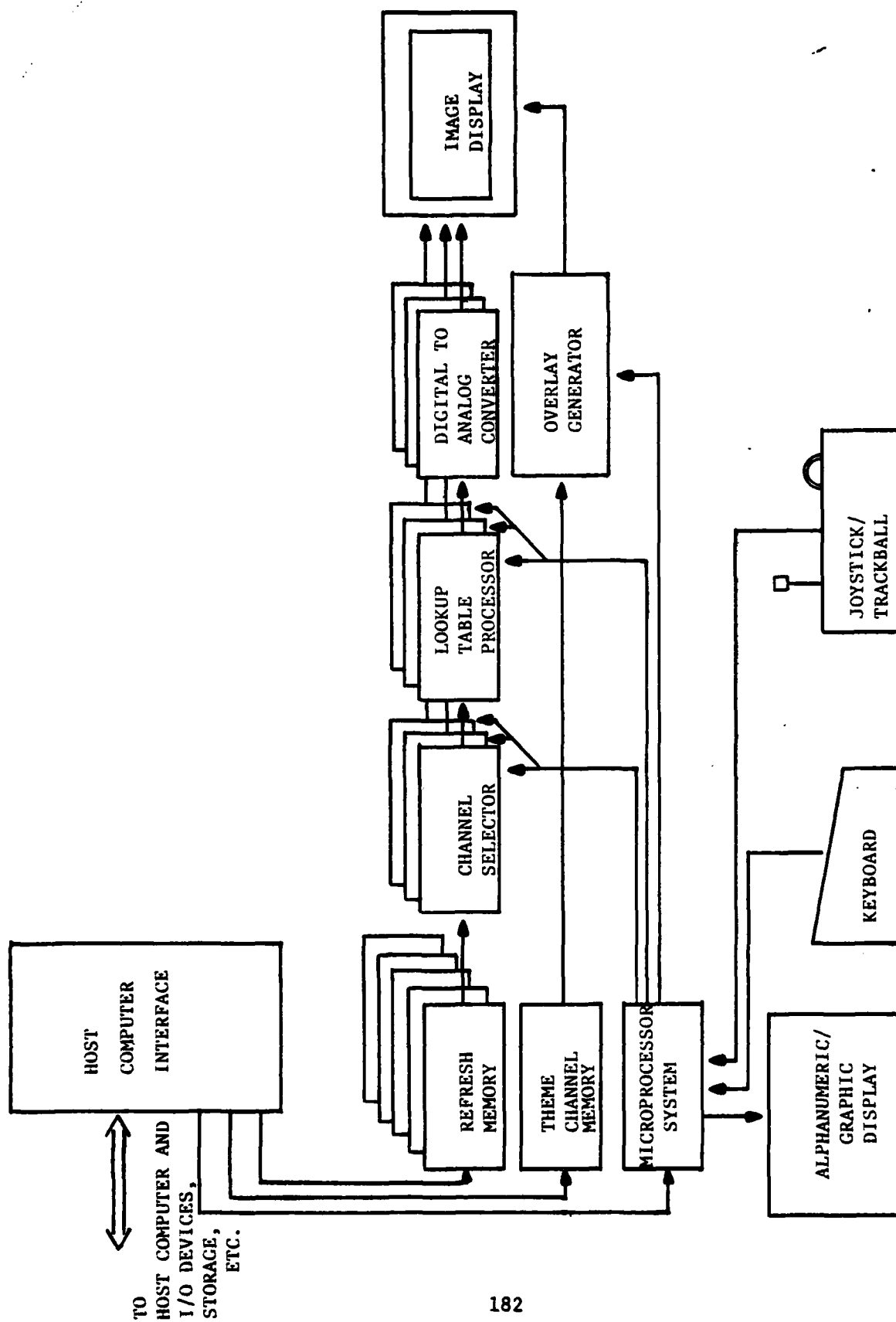


Figure 6-3. Image Analysis Terminal

stored in refresh can be allocated dynamically to any video channel on the display. Note that this function could be provided by operator controlled selector switches in order to further simplify the system.

As a baseline, it is highly desirable to provide a means of performing simple amplitude manipulation operations on the data for each channel so that the operator can control the display dynamically. For this purpose, three lookup table processors are included. These are simply programmable read only memories, loaded by the microprocessor with the desired transfer function and addressed by the data incoming from the refresh memory. (In the case where no manipulations are required the default for the table will be to load each location with its own address, thereby establishing the output data identical to the input).

The Digital/Analog Converters (DAC) generate the analog video signal to be applied to each of the three (red, green, blue) guns of the display. These video signals are mixed with analog video from the overlay generator which provides color thematic overlays in addition to any annotation and cursor generated graphics required.

The image display is a 512 x 512 pixel spatial resolution device with a precision color CRT. A higher resolution of 1024 x 1024 pixels could be used, but this would require a proportionately greater amount (four times) of refresh memory for each channel.

The system analyst/operator interacts with the image analysis process by means of an alphanumeric keyboard and uses the joystick and track ball as analog input devices for cursor control, dynamic control of lookup tables, etc. An alphanumeric/graphics display is used as a conversational device for menu/process option displays, display of statistics, one- and two-dimensional histograms, etc.

6.2.2 TERMINAL CAPABILITIES ENHANCEMENT

The capabilities of the basic interactive image analysis terminal can be enhanced by upgrading the components in three areas:

- a. The processor capabilities can be upgraded in the direction of providing autonomous operation.
- b. Local I/O peripherals can be incorporated as part of the terminal.
- c. The special purpose hardware capabilities can be increased to implement more complex algorithms.

These possibilities are discussed in more detail below.

The basic terminal design provides a microprocessor for process control functions only. All computations are provided by the host processor system, as are all I/O control tasks. By upgrading the capabilities of the processor many of these functions can be incorporated into the terminal itself, thereby reducing the need for communication with a host machine.

A typical terminal system incorporating a more sophisticated processor may also use local peripheral devices (such as tape units, film digitizers and film recorders, and disk storage capacity), for direct image data I/O and online storage. It must be recognized, however, that the same data is required by the host processor, and this imposes special requirements on the overall data I/O and host terminal communications. These considerations will be discussed in paragraph 6.3.

When enhancing the capabilities of special purpose hardware, it is often desirable to provide additional refresh memory channels. This allows the results of a complex algorithm to be stored for display in the normal manner,

and also for the results to be output to a local device (such as a film recorder) independent of other display oriented manipulations.

6.2.3 STANDALONE SYSTEM CONFIGURATIONS

In discussing standalone configurations it should be recognized that the intent of such a system is that all required image analysis functions can be performed in the local system. It does not, however, preclude the interfacing of the system to a major mainframe computer to take advantage of increased speed and processing capacity, or for seldom-needed resources that are shared with other systems as a facility resource.

A basic configuration for a standalone system is shown in Figure 6-4. It will be seen from this figure that the primary differences between a standalone system and an enhanced version of the basic terminal are:

- a. The inclusion of I/O devices and local mass storage
- b. Inclusion of a larger minicomputer with significant memory
- c. Modification of the refresh memory/special purpose hardware/display element architecture to enhance system flexibility
- d. Allowance for the interfacing of a special purpose processor (such as an array processor)
- e. Incorporation of an interface for a large mainframe computer as an optional "peripheral-like" device.

6.3 REMOTE SYSTEM COMMUNICATIONS

A key problem area in the implementation of a remote terminal system is providing image data to the local terminal for loading into refresh memory, as in the event that the terminal has a local I/O device such as a CCT unit transmitting data to the host processor for bulk processing.

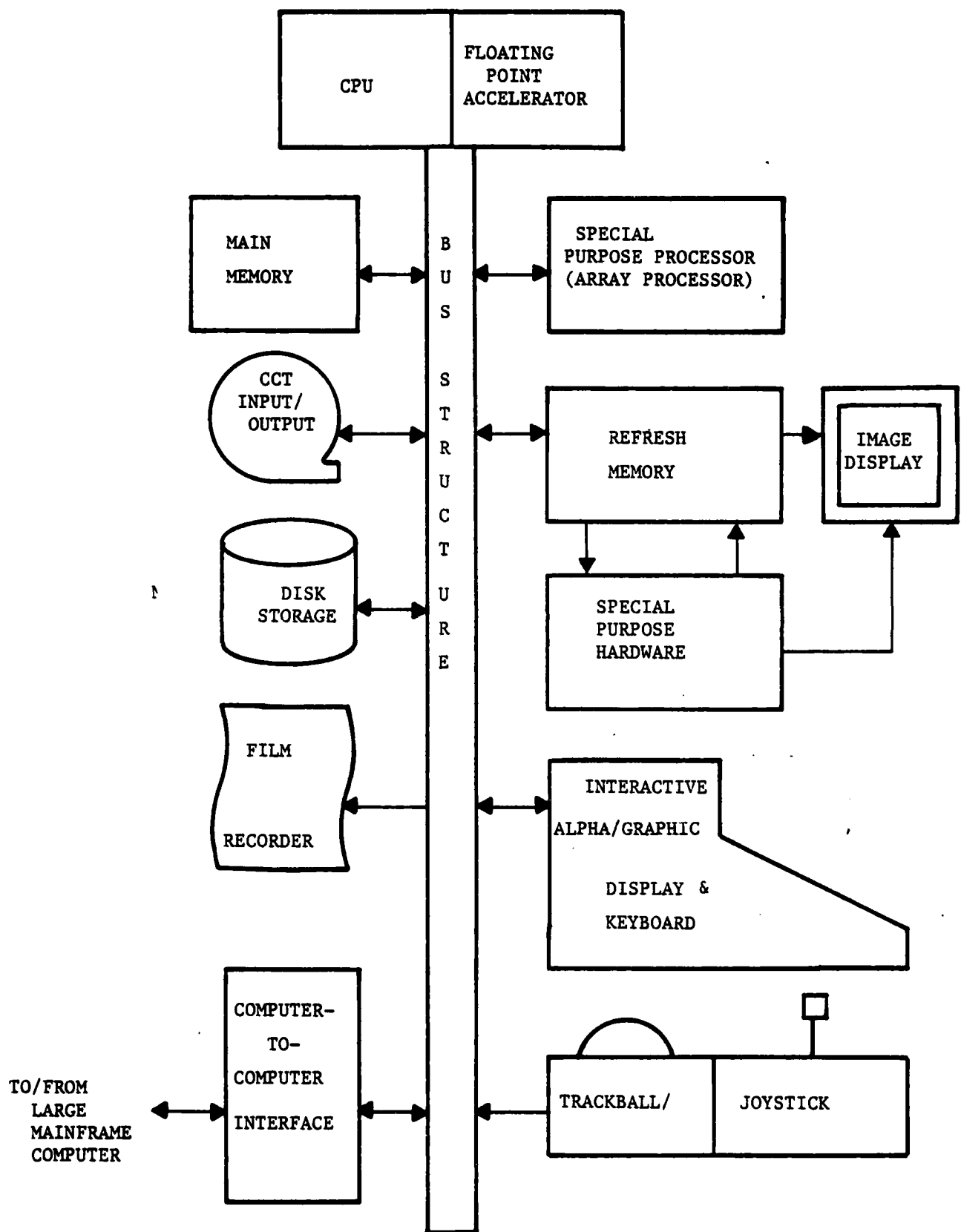


Figure 6-4. Standalone Image Analysis System

This problem is created because of the large volume of image data involved and the (relative) slowness of available communications links.

Typical telephone-based data links operate in the 2.4 - 56 kbps range; resulting in data transmission times as shown in Table 6-1 for a 512 x 512 pixel segment.

The updating of a color image with data processed by a remote host computer requires transmission of a total of $512 \times 512 \times 8 \times 3 = 6.3$ Mbits. Even with a dedicated 56 kbps link, this would require almost two minutes. When operating in an interactive environment, this is clearly an unacceptably long period of time. Similarly, loading a refresh memory from the host with a full Landsat-D segment (7 bands of 512 x 512 pixels) will take 4-1/2 minutes. Thus, any remote terminal system must be implemented in a manner so as to minimize the time penalties imposed by these transmission systems. In addition, recognition must be made of the operating expense of such a communications system. Lease cost of a 56 kbps line for a 1000 mile separation between terminals will be approximately \$4500 per month (AT&T long line rates).

In order to achieve a satisfactory data transfer rate for a minimal terminal capability, communications links with data rates on the order of 1.5 Mbps are required. Although technically feasible using communications satellite technology, such links would be extremely expensive.

An alternative approach to resolving the problem is the enhancement of local terminal capabilities in such a way that real-time traffic between host processor and terminal is minimized. Using this technique, the local terminal would approach the capabilities of the standalone terminal, but would rely on a central host processor for bulk processing of data in a batch mode. Transmission of processed imagery for immediate display would then be limited to

Table 6-1. Data Transmission Times in Seconds
for 512 x 512 Pixel Image

	1 BAND 1 BIT	1 BAND 8 BITS	3 BAND 8 BITS	7 BAND 8 BITS
56 KBPS	5	38	112	266
9600 BPS	28	219	565	1540
4800 BPS	55	437	1310	3080
2400 BPS	110	873	2610	6160

map overlays (theme channels) and products may be generated either at the central facility or at the local terminal. Distribution of raw image data may be by CCT loaded at the remote terminal, or by transfer of the raw data from the host processor in a "background" mode against a predetermined requirement, scheduled in advance, and recorded on an inexpensive local storage device.

If this method is used, a local ten-Mbyte disk can be used to store five segments of TM imagery. This could be downloaded over a dedicated low data rate link (9.6 kbps) in approximately two hours. This typically would approximate the time of a single analyst session at the terminal, and would also approximate the maximum rate at which an analyst could usefully interact with data to generate products or define batch processing requirements.

In this case, no image data traffic would pass from the terminal to the host processor - this traffic would consist of processing instructions only.

The disadvantage of this approach is, of course, that the advantages of the centralized host processor are compromised by the enhancements required of the remote terminal, and a system using relatively simple remote terminals is clearly impractical.

6.4 IMAGE DATA DISSEMINATION

The issue of image data dissemination has been alluded to in the previous section on remote terminal communications; however, it becomes of more significance for independent, standalone systems.

Three basic methods of dissemination are available, assuming that all data are obtained by a central COE archive facility.

- a. Data may be transmitted by dedicated communications links similar to those discussed in paragraph 6.3.

- b. Data may be disseminated as CCT products.
- c. Data may be disseminated using serial data recording such as video disk, video cassette or HDT products.

The technique that should be used is dependent on overall system architecture, availability of local archive capabilities and special input devices to handle serially recorded data, and the timeliness requirement for data receipt and processing at the local facility. As a general principle, however, HDT products should not be disseminated at a local level because of the high cost of the tape recorder hardware. For this reason, it will be assumed for subsequent discussions that a central facility disseminates Landsat-D data as CCT products.

SECTION 7

COST ANALYSIS

The preceding sections discussed the capabilities and typical configurations of an image analysis system. In this section a brief description of the cost tradeoff process to be applied is presented, together with a delineation of the cost drivers inherent in the design of candidate systems

7.1 COST TRADEOFFS

In making a cost tradeoff for any major system two key elements must be included: the initial cost of developing the system, and the expected cost of maintenance and operations over some period of time. To generate a complete life cycle cost the latter must be modified to account for cost escalation due to inflation.

For the purposes of this report, however, a simple comparison will be made for total cost of the system over a three-year period, based on the following criteria:

- a. All costs provided will be in basic 1979 dollars; no forward pricing or inflation factors will be used in these estimates.
- b. No provision will be made in the cost estimates for the physical facilities, land, security, or operational utilities (light, power, heat, etc.).
- c. An average labor rate of \$60 K per year through overhead and G&A (and before fee and contingency) will be used for each applied man throughout the design, fabrication, and test phases of the program. This value represents a reasonable mean between the higher paid senior engineers/managers and the lesser paid technicians/shop personnel.

- d. Published catalog prices will be used for estimating purchased hardware whenever possible; in a few cases, it may be necessary to rely on engineering estimates and past experience for estimates of purchased items. Costs will be included for contract support and similar support activity, in addition to the basic catalog price for all purchased items.
- e. Field rates will be used for estimating the cost of recurring station operations without regard to affiliation (contractor or Government personnel). These rates are through overhead and G&A per year.
 - 1. Manager/Engineers/Supervisors - \$48 K
 - 2. Lead Technicians/Operators - \$37 K
 - 3. Clerical and Support - \$27 K
- f. The cost estimates shall not preclude the use of a private (for profit) contractor for design, development and operation of the facility and provision for fee or profit at the rate of ten percent on total cost will be included. M & O training of Government personnel in this eventuality will not be included but should be relatively small (less than \$100 K).
- g. A contingency factor of ten percent will be included in the final total cost to account for some flexibility in requirements growth and unanticipated cost items. The ten percent fee included may also act as a contingency for those portions of the work performed by Government personnel.

7.2 SYSTEM COST DRIVERS

7.2.1 HARDWARE COSTS

Table 7-1 provides a list of cost estimates for the various hardware elements

Table 7-1. Hardware Cost Estimates (in Thousands of Dollars)

HARDWARE ITEM	COST ESTIMATE
<u>COMPUTERS</u>	DEC PDP 11/34 10 - 30 PDP 11/70 95 - 210 VAX 11/780 125 - 360
<u>STORAGE DEVICES</u>	300 MB DISK 24 - 50 6250 BPI CCT 30 - 60 HIGH DENSITY TAPE 250
<u>FILM RECORDER</u>	LASER BEAM 620 DRUM TYPE 80 - 120
<u>IMAGE ANALYSIS CONSOLE</u>	100 - 500
<u>ALPHANUMERIC/GRAPHIC TERMINAL</u>	15 - 25
<u>PRINTER/PLOTTER</u>	10 - 20
<u>ARRAY PROCESSOR</u>	60 - 200

that make up an image analysis system. These costs are based on manufacturers' catalog prices and represent typical ranges of cost for the major components. When assessing overall hardware cost for a system, an additional cost of interface hardware, cables and other miscellaneous hardware must be added. This is typically ten percent of the major hardware cost. In addition, a further ten percent is generally added to account for spare parts required for a period of three years of operations.

7.2.2 SOFTWARE COSTS

Software costs for an image analysis system are highly variable, depending on the degree of functional sophistication required in the system. For the purposes of this report, however, software costs can be based on the software structure outlined in Section 5. For the system for which this software was developed, this represented approximately 60,000 lines of code, mostly in FORTRAN. It can be assumed that a typical software production organization will average ten lines of code per day through code test, debug and documentation at a software module level. This represents some 48,000 man hours of effort, or approximately 25 man per years. This translates to \$1.5 million taking average cost per man year as \$60,000.

In practice, of course, much software will be available from other sources, particularly if a system is built from off-the-shelf components or subsystems, and thus this figure may be reduced significantly.

7.2.3 SYSTEMS ENGINEERING, PROGRAM MANAGEMENT AND OTHER COSTS

Systems Engineering provides for the overall design definition and integration of the various subsystem elements and all the tasks described as follows:

- a. Specification requirements - Provide the total system requirements and analysis. Included would be the appropriate requirements and

necessary purchasing instructions for hardware and site preparation requirements for the hardware.

- b. Interface control documents - Provides interface specifications between the designated hardware components. Identifies the specific formats for the input, output and interface points.
- c. System documentation - Organize and maintain all system documentation, including drawings, system wire lists, system layout, etc.
- d. Test and integration procedures - Provide plan for system test and integration.
- e. Test and integration support - Participate in system test and integration and provide all documentation.
- f. In-house and customer design reviews - Prepare formal customer design reviews and provide, as required, in-house design reviews.
- g. System integration and test - Provides for the subsystem and system level tests of the integrated components. This is representative of the final test at the contractor's facility prior to the shipping of equipment to the installation site.
- h. Site installation and checkout - Includes the actual shipment of equipment to the operational site as well as the performance of the final acceptance test on the system.
- i. Program management - Provides for the overall management and control of the entire systems development activity. Program management, administrative, and clerical support are included as well as providing for reports and communication with the customer.

For estimation purposes these elements can be assumed to be 25 percent of the hardware and software cost.

7.2.4 MAINTENANCE AND OPERATIONS

The maintenance and operations cost element provides for the yearly recurring costs that begin following the final acceptance test. The principal cost here is that of the onsite field personnel responsible for operating and maintaining the system, together with any inter-system communications costs. Costs are not included for consumable material items; however, replacement spare parts are assumed to require approximately ten percent of the hardware cost over a three-year period.

SECTION 8

CORPS OF ENGINEERS SYSTEM

In this section the various requirements of the Corps of Engineers and the capabilities and limitations of the three system concepts defined will be combined to establish candidate system designs for which cost tradeoffs can be made. In addition to the cost estimates, assessment of current state of the art and other considerations will be presented which will be introduced as modifying factors in establishing a suggested configuration for the COE system.

8.1 SYSTEM REQUIREMENTS ANALYSIS

Although Section 2 has presented a discussion of COE requirements for Landsat-D data analysis the requirements are not, as yet, sufficiently firm to establish a detailed set of system requirements at a district or even division level. Table 8-1 shows in summary form, however, the estimated total imagery requirements of each Corps division. Assuming a processing time of two hours per 512 x 512 pixel segment and an average of 10% of data processed from each scene a resulting time of 25 hours per TM scene is derived. If an analysis console is assumed to be operated two shifts per day for five days per week, a total of 4000 hours per year is available, providing sufficient processing time for 160 scenes per console per year. Thus the total Corps requirements may be estimated as being represented by a system with a total of 20 image analysis terminals (19 required in the various divisions plus one at Fort Belvoir). It is assumed that the configurations described will provide sufficient capacity for the batch processing requirements of each division with no additional hardware required.

8.2 CANDIDATE SYSTEM DESIGNS

In order to evaluate the three design concepts presented in Section 6, candidate designs have been prepared and the implementation and operational requirements

Table 8-1. Data Requirements by Division

	COVERAGE CYCLES	NUMBER OF SCENES	SCENES PER YEAR	SCENES PER DAY PERISHABLE	TERMINALS REQUIRED
NEW ENGLAND	6	15	90	3	1
NORTH ATLANTIC	7	23	161		1
SOUTH ATLANTIC	6	47	282		2
LOWER MISSISSIPPI	7	23	161		1
SOUTHWESTERN	4	84	336		2
MISSOURI RIVER	5	84	420	5	3
OHIO RIVER	5	33	165		1
NORTH CENTRAL	6	72	432	10	3
SOUTH PACIFIC	5	85	425	5	3
NORTH PACIFIC	6	54	<u>324</u>	<u>10</u>	<u>2</u>
TOTALS			2796	33	19

are described here. Each candidate design has been developed against the requirements described in paragraph 8.1, namely a system which makes 20 terminals available for image data processing to Corps of Engineers users. Each system is assumed to receive data as CCT products from a central distribution facility.

8.2.1 MULTIPLE INDEPENDENT SYSTEM CONFIGURATION

For this configuration the following hardware is assumed:

- a. Minicomputer (DEC PDP11/70 or equivalent) for host processor
- b. Array processor
- c. Two CCT units for data I/O
- d. 300 Mbyte disk storage
- e. Image analysis terminal containing sufficient refresh memory for 10 512 x 512 pixel segments, special purpose hardware for arithmetic transforms and simple multiband operations (such as parallelepiped classifier)
- f. Film image scanner/recorder.

A full software package as described in Section 5 will be provided.

For this configuration it is expected that input image data will be distributed on CCTs at nominal distribution cost. Maintenance and operations personnel requirements are estimated at four persons per terminal (one maintenance technician, two system operators and a supervisor).

8.2.2 COLLOCATED MULTITERMINAL SYSTEM

For this system the host processor is anticipated to be a network of three large minicomputers (VAX 11/780 or equivalent) hosting the twenty medium capacity terminals. The host processor system is assumed to include all disk storage and

CCT and film I/O devices and it is also assumed that an array processor is allocated to each VAX for bulk processing operations. The film recorder is assumed to be a high speed laser beam recorder. Software is assumed to be approximately 50% more complex than that for the independent terminals to account for the increased load of multi-tasking required to support the terminals and for the communications between processors.

Each terminal is a standalone unit with ten channels of refresh memory and special purpose hardware. Maintenance and operations personnel requirements are estimated as a total of 48 persons (one CPU operator, two maintenance technicians, 20 console operators and one supervisor per shift).

8.2.3 REMOTELY LOCATED MULTITERMINAL SYSTEM

This configuration uses the same host system as the centrally located multiterminal system. Each terminal, however, is provided with a 300 Mbyte disk and a single CCT drive to provide autonomous data storage and I/O capability using a small minicomputer (PDP 11/34) as a controller. In addition, each terminal location is assumed to be connected to the host processor system by a dedicated 56 kbps data link. Maintenance and operations personnel requirements for this configuration are 85 persons (one CPU operator and one maintenance technician per shift plus one supervisor for the host processor; two operators, one maintenance technician and one supervisor for each terminal).

8.2.4 CUSTOM CONFIGURED STANDALONE SYSTEM

Table 8-1 shows that several of the COE divisions require more than one terminal to satisfy their image analysis requirements. A compromise system can be developed which takes advantage of the fact that a standalone system based on a PDP 11/70 and an array processor can support more than one analysis console. Thus, the custom configuration will consist of a PDP11/70 host with an AP for

each division, plus one, two or three analysis consoles, as required. each with its own disk storage and alphanumeric/graphics terminal. CCT, printer/plotter and film recorder resources would be common resources accessed through the host minicomputer. Staffing for this configuration would be 52 persons (two operators per console plus one maintenance technician and one supervisor per location).

3.3 SYSTEM SELECTION

System selection criteria are for the most part based on cost comparisons, however, other criteria which cannot be compared accurately are also important. Table 8-2 provides a comparison of the hardware complement for each option and Table 8-3 compares the total costs for implementation plus three years operations for each of the concepts defined.

From these tables the most economically attractive configuration is the collocated multi-terminal system. This configuration suffers from the disadvantages stated in Section 6, however, in that it requires considerable travel on the part of the local user at the division and district level and will work against the involvement of the individual console operators and analysts in becoming experienced in dealing with local problems and local data.

The best compromise appears to be the customized standalone terminal configuration, since this provides the advantages of a locally oriented system at very little additional cost.

Table 8-2. Hardware Matrix for the Candidate Configurations

CONFIGURATION OPTION	EQUIPMENT DESCRIPTION	UNIT PRICE	NUMBER REQUIRED	TOTAL PRICE	COST INFORMATION
<u>STAND ALONE TERMINAL</u>					
	MINICOMPUTER (PDP11/70)	160K			DEC CATALOG
	DISK STORAGE (300 MB)	30K			VENDOR CATALOG
	CCT UNITS (2 EA)	72K			VENDOR CATALOG
	FILM RECORDER	120K			OPTRONICS CATALOG
	ARRAY PROCESSOR	80K			VENDOR QUOTE
	IMAGE ANALYSIS CONSOLE	130K			COMTAL CATALOG
	ALPHA/GRAPHICS TERMINAL	18K			VENDOR CATALOG
	PRINTER/PLOTTER	15K			VENDOR CATALOG
	TOTAL	625K	20	12.3 MILLION	
<u>COLLOCATED MULTI-TERMINAL</u>					
	HOST SYSTEM:				
	COMPUTER (VAX 11/780, 3 EA.)	1000K			DEC CATALOG
	DISK STORAGE (300 MB, 20 EA.)	600K			VENDOR CATALOG
	CCT UNITS (12 EA.)	432K			VENDOR CATALOG
	LASER BEAM RECORDER (2 EA.)	1250K			GE ESTIMATE
	ARRAY PROCESSOR (3 EA.)	240K			VENDOR QUOTE
	MISC. PERIPHERALS (PRINTERS, ETC.)	150K			GE ESTIMATE
	TOTAL	3672K	1	3.7 MILLION	
	TERMINALS:				
	IMAGE ANALYSIS CONSOLE	130K			COMTAL CATALOG
	ALPHA/GRAPHICS TERMINAL	18K			VENDOR CATALOG
	PRINTER/PLOTTER	15K			VENDOR CATALOG
	TOTAL	163K	20	3.3 MILLION	
	TOTAL SYSTEM COST			7.0 MILLION	

Table 8-2. Hardware Matrix for the Candidate Configurations (Continued)

CONFIGURATION OPTION	EQUIPMENT DESCRIPTION	UNIT PRICE	NUMBER REQUIRED	TOTAL PRICE	COST INFORMATION
<u>REMOTE MULTITERMINAL</u>	HOST SYSTEM:				
	COMPUTER (VAX 11/780, 3 EA.)	1000K			DEC CATALOG
	DISK STORAGE (300 MB, 20 EA.)	600K			VENDOR CATALOG
	CCT UNITS (12 EA.)	432K			VENDOR CATALOG
	LASER BEAM RECORDER (2 EA.)	1250K			GE ESTIMATE
	ARRAY PROCESSOR (3 EA.)	240K			VENDOR QUOTE
	MISC PERIPHERALS (PRINTERS, ETC.)	150K			GE ESTIMATE
	TOTAL	369K	20	7.4 MILLION	
	TOTAL SYSTEM COST			11.1 MILLION	
<u>CUSTOMIZED S. ANDALONE TERMINAL</u>	HOST PROCESSOR SYSTEM:				
	MINICOMPUTER (PDP 11/70)	160K			DEC CATALOG
	CCT UNITS (2 EA.)	72K			VENDOR CATALOG
	FILM RECORDER	120K			OPTRONICS CATALOG
	ARRAY PROCESSOR	80K			VENDOR QUOTE
	PRINTER/PLOTTER	15K			VENDOR CATALOG
	TOTAL	447K	11	4.9 MILLION	
	ANALYST TERMINALS:				
	IMAGE ANALYSIS CONSOLE	130K			COMTAL CATALOG
	ALPHA/GRAPHICS TERMINAL	18K			VENDOR CATALOG
	DISK STORAGE (300 MB)	30K			VENDOR CATALOG
	TOTAL	178K	20	3.6 MILLION	
	TOTAL SYSTEM COST			8.5 MILLION	

Table 8-3. Cost Comparison Between Configuration Options (in Millions of Dollars)

COST ELEMENT	STANDALONE TERMINAL	COLLOCATED MULTITERMINAL	REMOTE MULTITERMINAL	CUSTOMIZED STANDALONE
<u>IMPLEMENTATION:</u>				
HARDWARE	12.3	7.0	11.1	8.5
SOFTWARE	1.5	2.3	2.3	1.5
SYSTEM ENGINEERING	3.1	1.8	2.8	2.2
(INCLUDES PROGRAM MGMT., INSTALLATION & TEST, ETC.)				
TOTAL SYSTEM COST	16.9	11.1	16.2	12.2
<u>MAINTENANCE AND OPERATIONS:</u>				
SPARES	1.2	0.7	1.1	0.8
MANPOWER	9.5	5.4	10.1	6.1
COMMUNICATIONS	-	-	3.1	-
(ASSUMES 19 TERMINALS, AVERAGING 1000 MILES EACH FROM CENTRAL FACILITY)				
TOTAL M&O COST FOR 3 YEARS	10.7	6.1	14.3	6.9
PROGRAM COST	27.6	17.2	30.5	18.1
COST THROUGH 10% FEE, 10% CONTINGENCY	33.4	20.8	36.9	21.9

SECTION 9

CONCLUSIONS

This report has provided an analysis of requirements and capabilities based on the activities of the Corps of Engineers and the state of the art in image analysis for an advanced satellite hardware/software system. Such a system would be used by the Corps of Engineers for analysis of image data from the Landsat-D spacecraft.

In considering all technical and cost issues involved, it is concluded that an image analysis system of independent terminals configured to satisfy local needs at the COE division level, the "Customized Stand Alone Terminal System" is the recommended system approach:

- o Employed at the division level, the customized system would consist of 11 host minicomputers (PDP-11/70 type) with necessary peripherals interfaced to 20 customized analyst terminals.
- o Hardware costs for the customized systems at division are estimated to be 8.5 million dollars; software and systems engineering are expected to be 3.7 million dollars; maintenance and operations costs for three years are estimated to be 13.8 million dollars.
- o The recommended system excludes the purchase of expensive High Density Tape systems and the purchase of expensive laser printers; standard CCT data are the expected input; reasonable-cost drum film recorders are the expected hardcopy output devices.
- o A good share of the software is expected to come from off-the-shelf at considerably less than development costs.
- o Software systems for the recommended system may still change in that remote sensing applications of Landsat data are still being developed,

demonstrated and further refined within the COE.

- o The presidential directive of November 1979, designating NOAA to manage operational remote sensing activities from space, has made many issues unclear on data acquisition, ability to produce products on a timely basis, and restrictions on directly accessing raw data. All of the forgoing have a direct bearing on the results of this study and may invalidate some of these results and conclusions.

APPENDIX A

THEMATIC MAPPER GEOMETRY

The thematic mapper (TM) is a Ritchey-Chretien telescope with mechanical scanning of the ground scene and solid state sensors at the focal plane. The Ritchey-Chretien approach permits a compact package through the use of folded optics. These optics give very good image correction for coma, spherical aberration and astigmatism. All the optical elements used in the imaging train are shown schematically in Figure A-1.

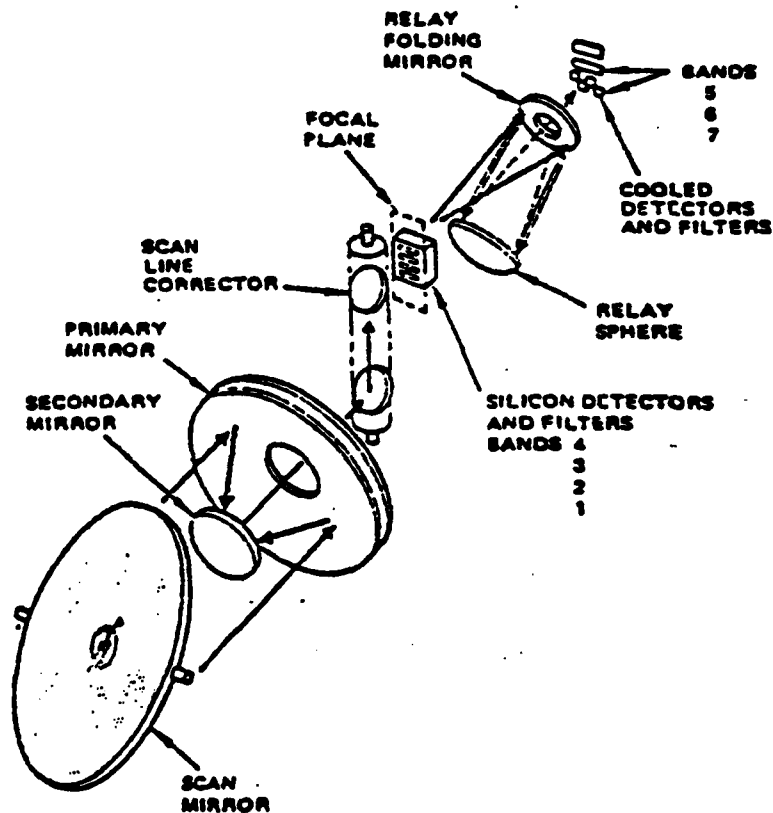


Figure A-1. Thematic Mapper Optical System

A good representation of the TM and its relative orientation with the ground scene may be seen in Figure A-2. Landsat-D is depicted as over the equator traveling north to south and the scan mirror is just ready to start a reverse scan from west to east. The scan mirror's function is to scan the ground scene perpendicular to the spacecraft's orbital plane in both directions. It directs light from the desired ground scene to the primary and secondary mirrors which gather and then image the rays at the primary focal plane where 64 visible band detectors are located (bands 1, 2, 3, 4). Located just behind the primary mirror is the scan line corrector whose design purpose is to prevent any cross scan image at the focal plane due to the spacecraft's ground speed. The relay optics consist of the relay mirror (the one with the hole in it) and the spherical mirror which re-forms the ground scene image at the secondary focal plane where 36 IR detectors are located (bands 5, 6, 7).

Spacecraft coordinates shown are also colinear with the TM coordinates. +X is in the direction of Landsat motion and +Z is in the direction of local geodetic vertical.

Also shown in Figure A-2 is the ground projection of the individual detectors which can be visualized as sliding back and forth along the ground in the direction of the forward and reverse scans.

A single Landsat-D image, nominally 170KM by 185KM, will be formed by 362 successive scans of the TM as illustrated in Figure A-3. Each individual scan is nominally comprised of 613,040 data points or pixels. These pixels are created each time an individual detector is sampled during the scan. Figure A-4

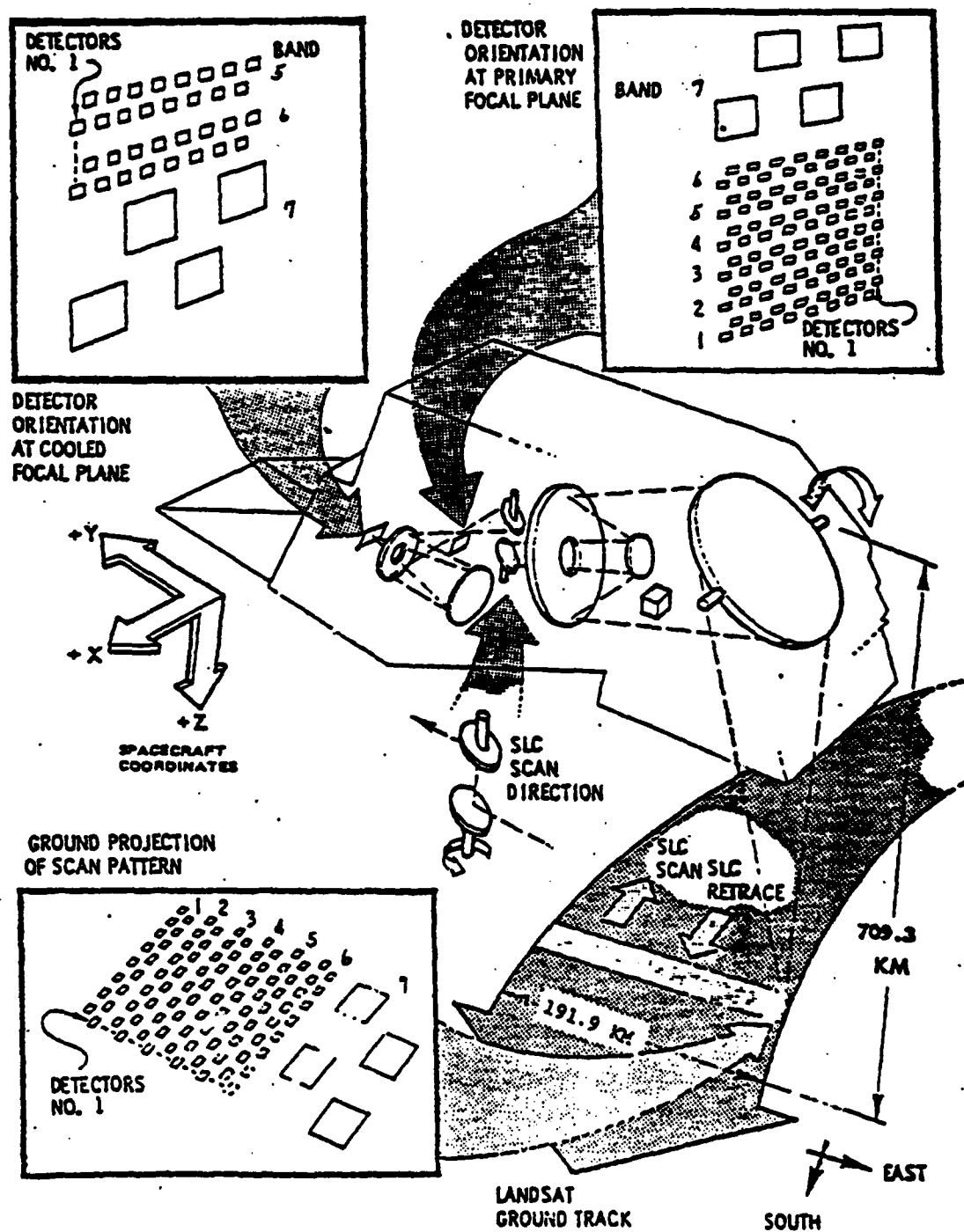


Figure A-2. TM Detector Array Projection Along Scan

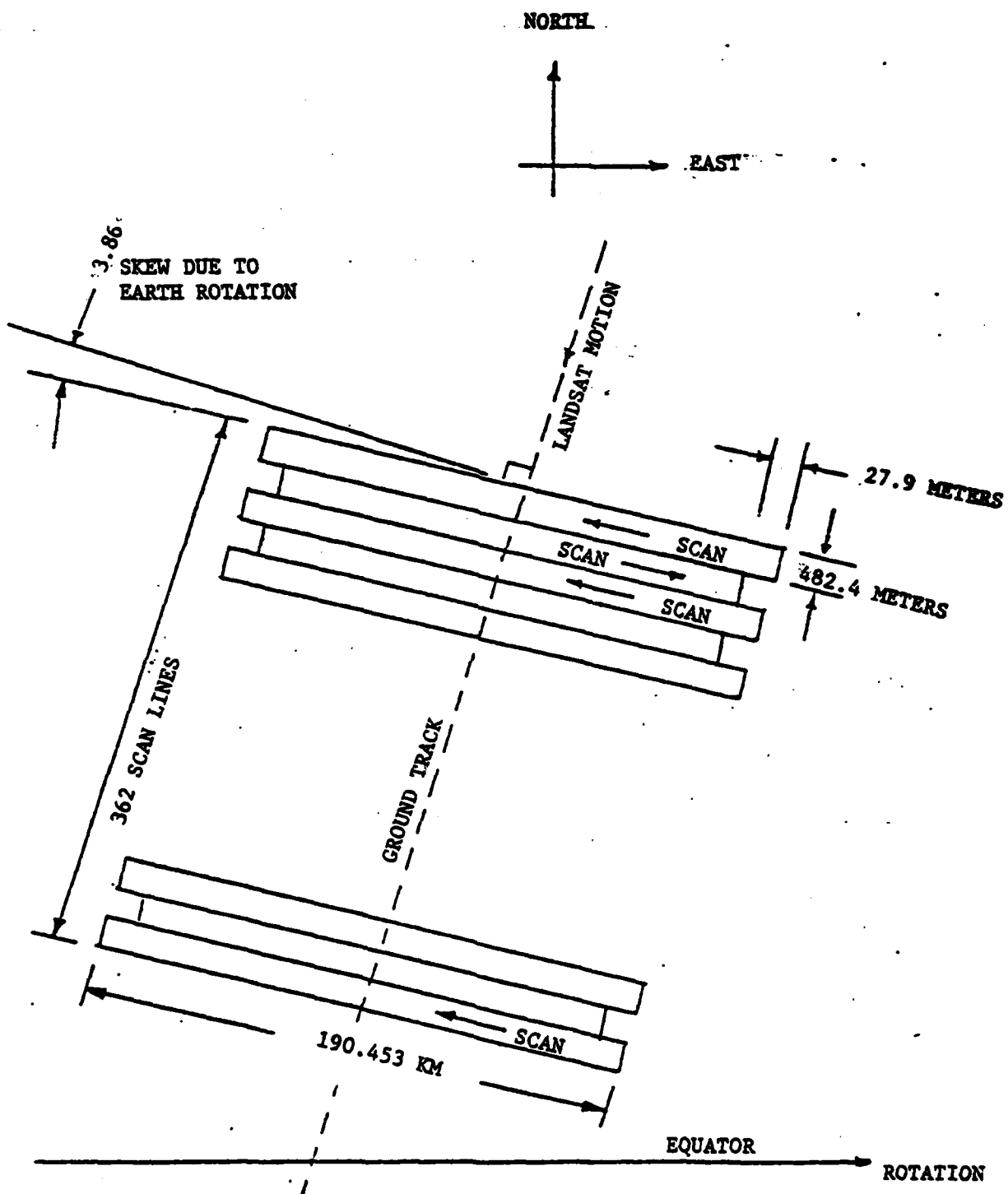


Figure A-3. Scene Conditions at the Equator

shows a scaled layout of all the detector arrays as they appear on the primary focal plane. Bands 1, 2, 3, 4, 5, 7 have 16 detectors each and band 6 has 4 detectors. Separation distance between the bands, along the Y_{fp} axis are given in microradians.

The sequence and timing by which each individual detector senses the ground scene is as follows. Each of the 16 detectors in bands 1, 2, 3, 4, 5 and 7 is sampled 6320 times and each of the four detectors in band 6 is sampled 1530 times during one scan. Thus, one scan contains $(6320 \text{ pixels/detector}) \times (16 \text{ detectors/band}) \times (6 \text{ bands}) + (1530 \text{ pixels/detector}) \times (4 \text{ detectors/band}) \times (1 \text{ band}) = 613,040$ samples or unique pixels. Table A-1 gives the relationship between band number, detector number, pixel number, and time increment for all the TM detectors during one scan. Since a ground scene image is always present at both focal planes, sample time is actually when the sensed ground scene is "held" by the sampling circuits.

At the start of each scan, detectors 1, 3, 5...15 are sampled first. Then after 4.806 microseconds, detectors 2, 3, 6...16 are sampled. This sequence repeats throughout the scan. Since detectors 1, 2, 3, 4 or band 7 have an equivalent linear dimension of four times the other detectors, they are sampled at intervals of 4×4.806 microseconds.

Individual detectors within a band are staggered with respect to one another as shown in Figure A-5. Notice that the even numbered detectors in bands 1, 2, 3, 4, 5 and 7 are separated from the odd numbered detectors by 2.5 IFOVs or 2.5 pixels.

Table A-1. Detector Sampling Scheme and Pixel Numbering

TIME IN MICROSECONDS	NUMBER OF TIME STEPS	BANDS 1, 2, 3, 4, 5, 7		BAND 6	
		DETECTORS 1, 3, 5---15	DETECTORS 2, 4, 6---16	DETECTORS 1 AND 3	DETECTORS 2 AND 4
0	0	PIXEL 1	PIXEL 1	PIXEL 1	
4.806	1	PIXEL 2	PIXEL 2		
9.612	2	PIXEL 3	PIXEL 3		
	3	PIXEL 4	PIXEL 4		
	4	PIXEL 5	PIXEL 5		PIXEL 1
	5	PIXEL 6	PIXEL 6		
	6	PIXEL 7	PIXEL 7		
	7	PIXEL 8	PIXEL 8		
	8	PIXEL 9	PIXEL 9		
	9			PIXEL 2	
	10				
	11				
	12				
	13				
	14				
	15				
	16			PIXEL 3	
	17				
	.			.	.
	.			.	.
	.			.	.
	.			.	.
	.		PIXEL 6320		
60743	12639				
SAMPLE TIME EQUATIONS		$t = 2 (n_p - 1) \Delta t$	$t = 2 (n_p - 1) \Delta t + \Delta t$	$t = 8 (n_p - 1) \Delta t$	$t = 8 (n_p - 1) \Delta t + 4 \Delta t$

n_p = PIXEL NUMBER

$$\Delta t = \frac{(.060743 \text{ SEC/SCAN})}{\{(6320) (2) - 1\}} = 4.806 \text{ sec}$$

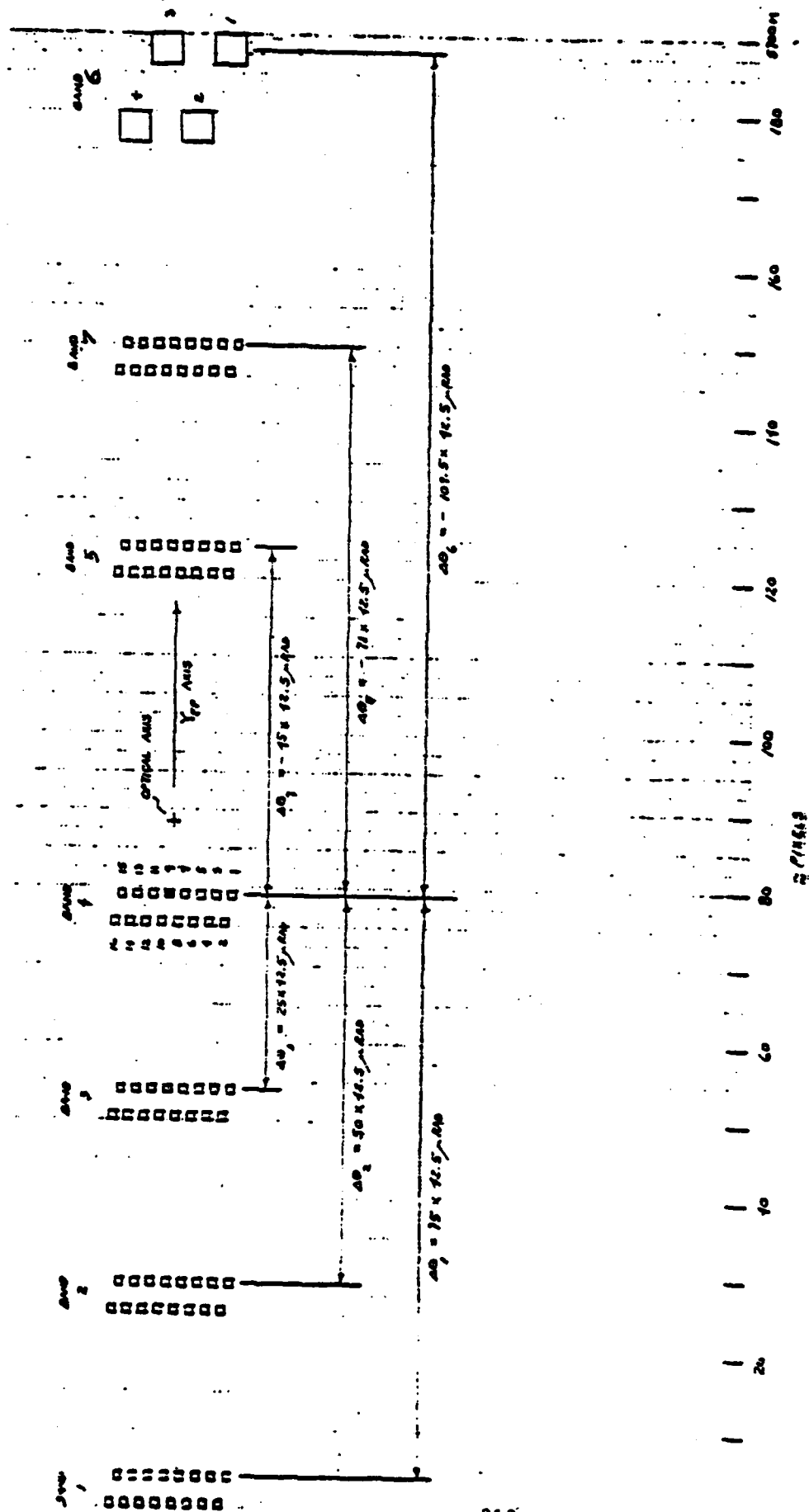


Figure A-4. Thematic Mapper Detector Arrays

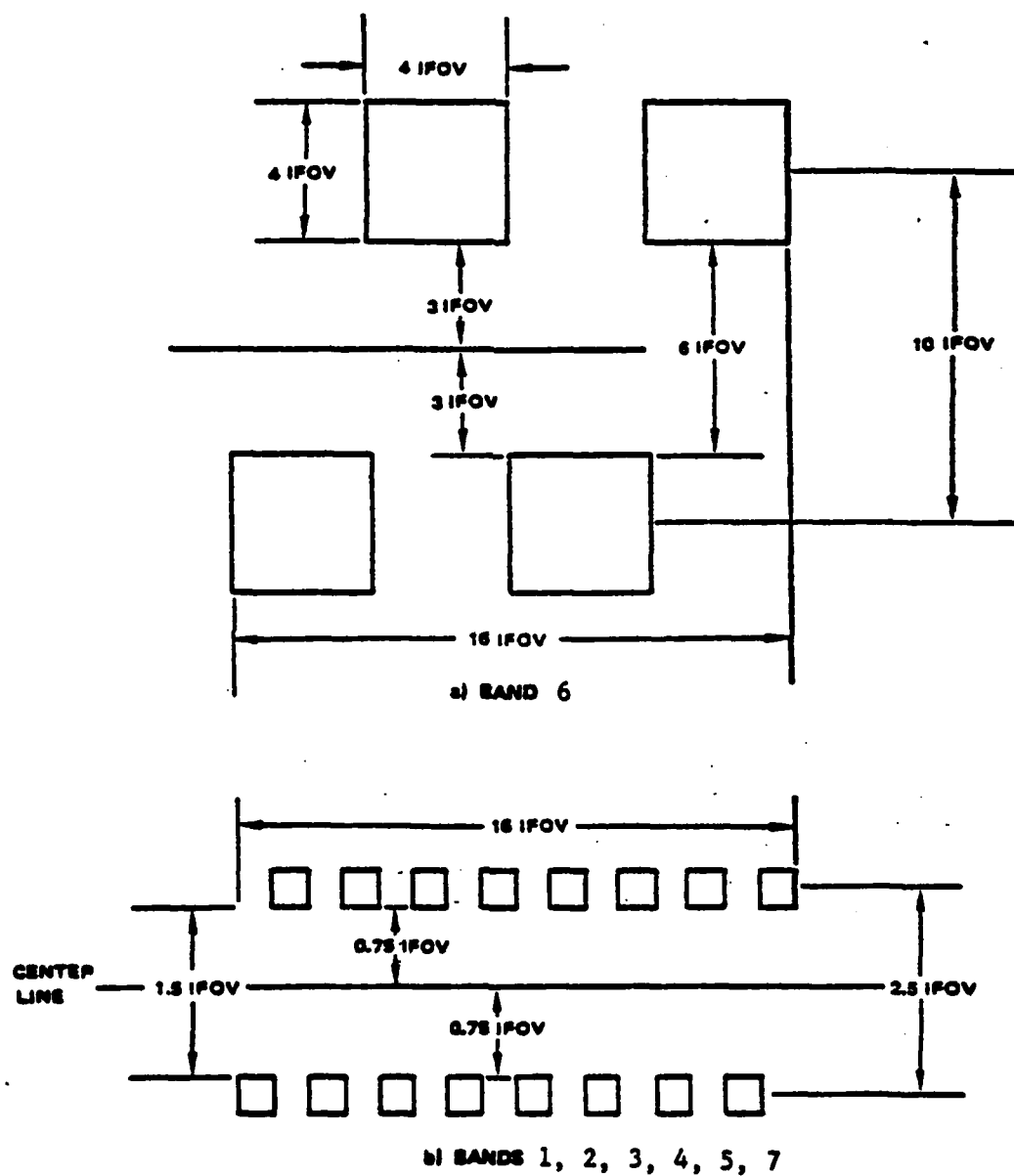


Figure A-5. Detailed Detector Layouts

This spacing, combined with the timing sequence already described, creates a ground sampling pattern as shown in Figure A-6 (for a west to east scan) and by Figure A-7 (for an east to west scan).

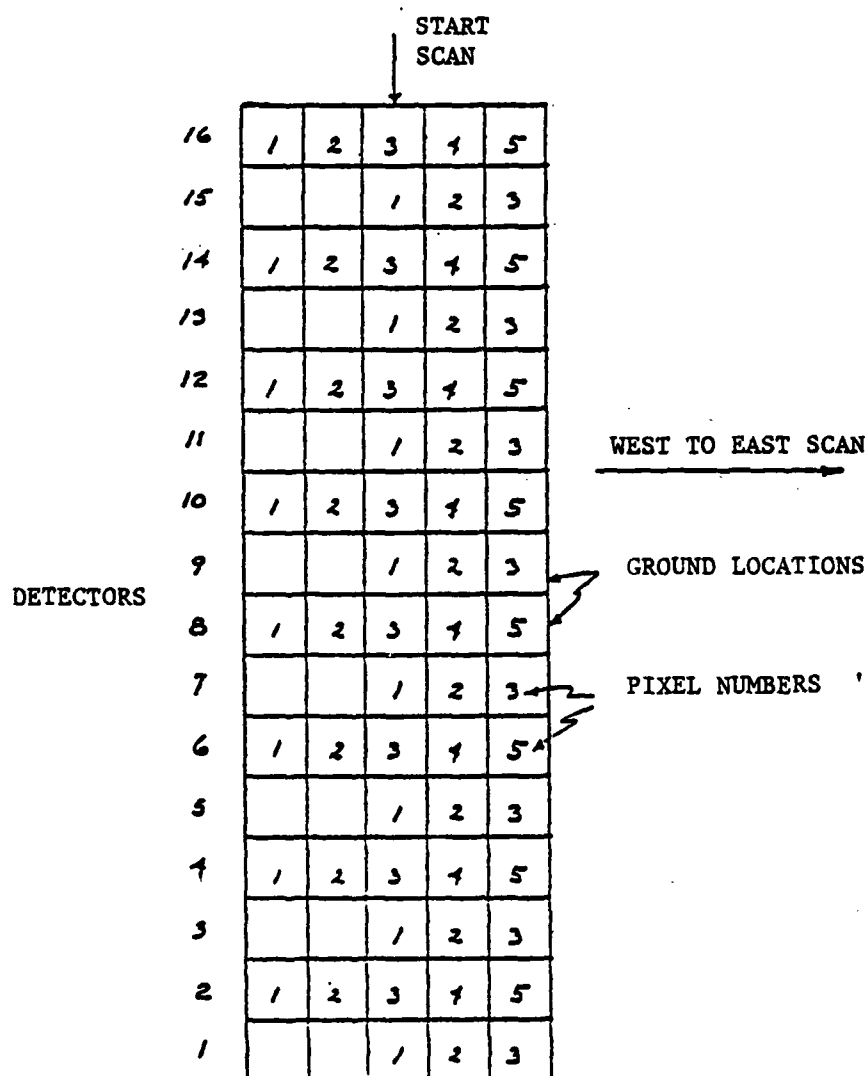


Figure A-6. Ground Pixel Pattern for Bands 1, 2, 3, 4, 5, 7
West to East Scan

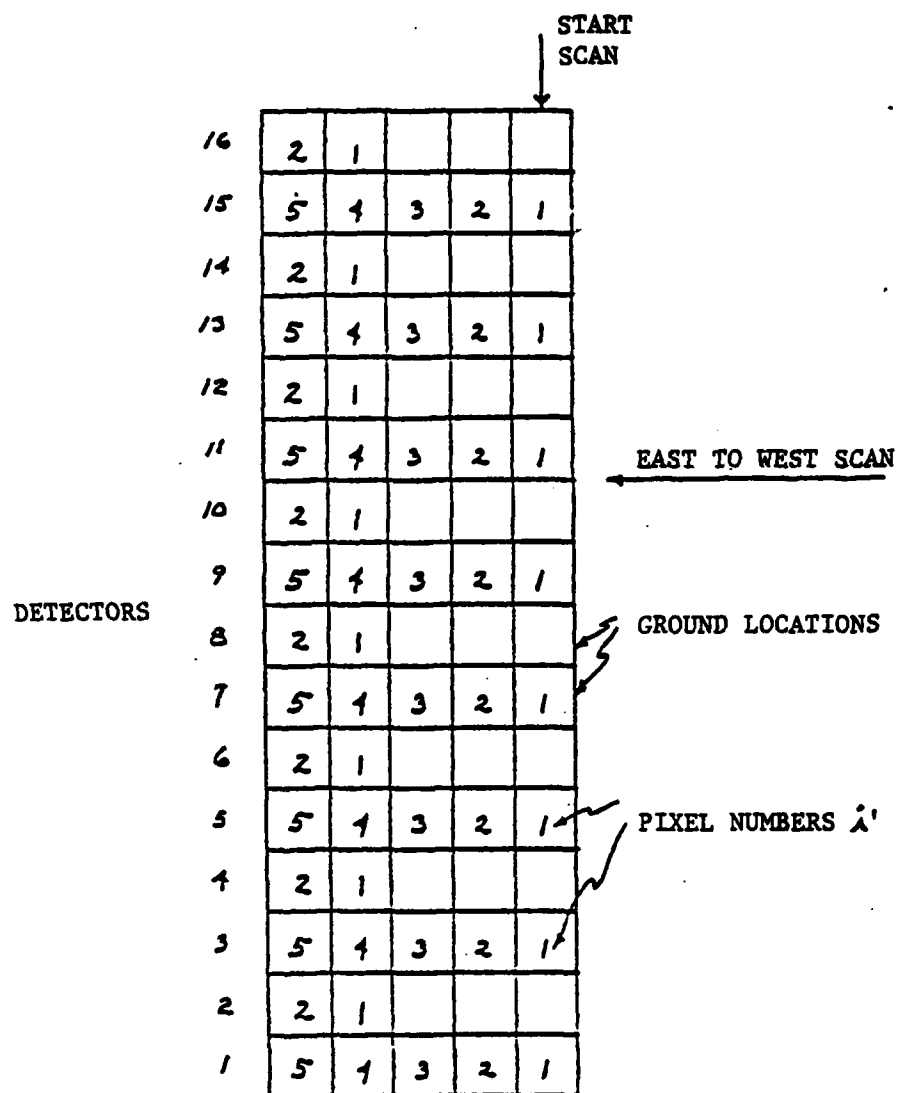


Figure A-7. Ground Pixel Pattern for Bands 1, 2, 3, 4, 5, 7
East to West Scan

REFERENCES

1. Image Processing and Analysis System Facility Design Guide, D. M. Smith, GE Document 79SDB001.
2. Technical Description of Digital Image Processing System. Ground Systems Department, General Electric Company, Space Division, Daytona Beach, Florida.
3. Landsat-D Ground Segment: Landsat Assessment System Special Engineering Studies, General Electric Company, Space Division, Lanham, MD.
4. Image Processing Investigations, G. J. Chafaris, GE Document 77SDB002.
5. U.S. Army Corps of Engineers Remote Sensing Manual.
6. Memorandum for Record, L. P. Murphy, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, VA. February 29, 1979.
7. Memorandum for Record, L. P. Murphy, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, VA. August 1, 1979.
8. Landsat-D: Corps of Engineers Interface with Advanced NASA Ground Systems Study. U.S. Army Corps of Engineers. Engineer Topographic Laboratories, Fort Belvoir, VA. ETL-0151 June 1978.

LIST OF ABBREVIATIONS

AP	Array Processor
AT&T	American Telephone and Telegraph
b	Bit
B	Byte
BIL	Band Interleaved by Line
bpi	Bits per inch
bps	Bits per second
Bps	Bytes per second
BSQ	Band Sequential
CCT	Computer Compatible Tape
COE	Corps of Engineers
cm	Centimeter
CPU	Central Processor Unit
CRT	Cathode Ray Tube
DMA	Direct Memory Access
Domsat	Domestic Communications Satellite
EDC	EROS Data Center
EIS	Environmental Impact Statement
EROS	Earth Resources Operational System
FFP	Federation of Functional Processors
G&A	General and Administrative Costs
GB	Gigabytes
GCP	Ground Control Point

GCR	Group Code Recorded
GDT	Graphics Display Terminal
GSFC	Goddard Space Flight Center
HDT	High Density Digital Tape
HDT-A	Archival HDT
HDT-P	Product HDT
HDT-R	Radiometrically corrected HDT
HW	Hardware
IAC	Image Analysis Console
IAS	Image Analysis System
IAT	Image Analysis Terminal
IFOV	Instantaneous Field of View
IGF	Image Generation Facility
I/O	Input/Output
IR	Infrared
K	Thousand
KB	Kilobytes
kbpi	Kilobits per inch
kbps	kilobits per second
kBps	Kilobytes per second
KM	Kilometers
m	Meter
Max	Maximum
MB	Megabytes

Mbps	Megabits per second
MBps	Megabytes per second
M-C	Multi-cell
MCR	Monitor Console Routines
Min	Minimum
mm	Millimeter
MMF	Mission Management Facility
MMS	Multimission Modular Spacecraft
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
N-D	N-dimensional
NOAA	National Oceanographic and Atmospheric Administration
NRZI	Non Return to Zero Inverted
ns	Nanosecond
PE	Phase Encoded
S/C	Spacecraft
Sec	Seconds
SP	Special Purpose
TDRSS	Tracking and Data Relay Satellite System
TM	Thematic Mapper
TV	Television
UV	Ultraviolet
1-D	One Dimensional
λ	Wavelength
μ M	micro-meter